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TRAUMA INDICES AND APPLICATIONS,

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INTRODUCTION

A considerable effort has been devoted to the development of a broad class of trauma indices covering a range of patient conditions. The original work was begun in 1973 in cooperation with the Maryland Institute for Emergency Medicine (MIEM). Efforts have continued in MIEM and also with surgeons at Washington Hospital Center and Monmouth Medical Center.

The focus of the efforts has been to develop a number of different indices based on anatomical diagnosis and physiological and biochemical data and to correlate these indices with mortality.

METHODS

The indices evolved from pattern recognition analyses of over 60 physiological and biochemical variables. Each of the variables and many combinations of variables were evaluated using the concept of information gain. This number, which measures the predictive "power" of an index (or variable), can be interpreted as the average amount by which one could alter the prognosis of each patient of a patient group when provided with a given value of the index for each member of the group. Mathematically, the information gain, E, is written

$$E = \sum_{i=1}^n |P_D - P_{D,i}| P_i$$

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where P_D is the a priori probability of death, $P_{D,i}$ is the probability that the patient will die given that the index takes on a value in the interval i , and P_i is the probability that the index assumes a value in the interval i . The range of values of the index is divided into n intervals for the calculation. The maximum value of information gain for a patient population is $2P_D(1-P_D)$. If an index were a perfect discriminator in a treatment facility where the death rate was 50%, information gain would be 0.50.

On the basis of these computations, advice from clinicians, and practicality, the indices were derived.

For each of the indices, probability of mortality curves were obtained by fitting the data to a logistic model of the form:

$$P_D(X;B) = \frac{1}{1 + e^{-A}}$$

where

$P_D(X;B)$ = the probability of death,

$$A = B_1 + B_2X_2 + \dots + B_nX_n,$$

(1, X_2, \dots, X_n) is a vector of variables,

and

(B_1, \dots, B_n) is a vector of weights associated with the variables.

The variables may be physiological or biochemical measurements, indices, age, and may include "indicator" variables; (e.g., for sex, 1 = males and 2 = females). The weights were obtained by the Walker-Duncan regression algorithm (1) which produces approximate maximum likelihood estimates. In the regression calculation, the dependent variable $P_D(X;B)$ used in estimating B was assigned a 0 if the patient lived and a 1 if death ensued. Approximate 95% confidence bounds on the curve were computed by the method of Kendall and Stuart (2).

A further refinement associated with the development of the indices involved calculating the expected misclassification rates associated with the index. A decision rule which predicted survival if the probability of death was less than 0.5 and death otherwise was used as a basis for the prediction of individual survival. Expected misclassification rates were then computed for various patient sets.

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Another methodology introduced is known by the acronym PER. P is the a priori probability of death for the study population, E is the information gain described earlier and R is the relative information gain of the index against a perfect predictor. PER is a useful tool for evaluating an index. If P is small, (say .05) then an index must be very good in order to provide better predictions of patient outcome than a random decision rule. PER can be used to characterize any index in terms of its predictive power.

INDICES

A generalized patient status index called the CHOP Index was developed for use as an overall predictor of patient mortality (3). The CHOP Index is based on four variables: serum creatinine (C), hematocrit (H), serum osmolality (O), and systolic blood pressure (P). It is the square root of the sum of the squares of the deviations (measured in standard deviation units) from normal average values of the four variables; that is,

$$\text{CHOP Index} = \sqrt{\left(\frac{C-1.0}{0.5}\right)^2 + \left(\frac{H-37.0}{6.0}\right)^2 + \left(\frac{O-292.0}{15.0}\right)^2 + \left(\frac{P-137.0}{21.0}\right)^2}$$

In mathematics, this quantity is called Euclidean distance and reflects the difference between an actual patient state and a desired patient state. In each of the squared terms in the sum under the radical, the number in the numerator is the estimated normal average value of the variable, and the number in the denominator is the estimated standard deviation of that variable. For example, 37.0 is the average for hematocrit (H) and 6.0 the standard deviation. These estimates of the averages and standard deviations were obtained from final recorded values from 350 survivors.

A Respiratory Index (RI) was developed as an indicator of a trauma patient's respiratory state (4). The purpose of the RI was to (a) compare therapy in patients with respiratory complications in various institutions, (b) compare variations in treatment, and (c) graphically represent a patient's progress or deterioration as an adjunct to patient care. It was computed by the formula:

$$\text{Respiratory Index} = \frac{|(P_B - P_{H_2O}^T) F_{IO_2} - P_aCO_2| - PaO_2}{PaO_2}$$

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where

P_B = barometric pressure.

$P_{H_2O}^T$ = alveolar water vapor pressure at the patient's temperature T (approx. 47 mm Hg).

F_{IO_2} = fractional concentration of O_2 in inspired gas.

$PaCO_2$ = arterial partial pressure of carbon dioxide. In this formula we assume it to be equal to the alveolar partial pressure of the carbon dioxide.

PaO_2 = arterial partial pressure of oxygen.

A Renal Index (REI) was developed as an adjunct method for evaluation of renal failure and indications for hemodialysis in trauma patients (5). The parameters for the study of renal function were the blood urea nitrogen (BUN), the serum creatinine, and the hourly urine volume. Admission and daily measurements were made of the serum creatinine and the BUN. Each patient's 12-hour urine volume was measured and converted to a normalized value called Urine Vol_N. The daily values of the above parameters were used to compute an index of renal function using the formula:

$$\text{Renal Index} = 1/3 (Cr_N + BUN_N + \text{Urine Vol}_N).$$

Cr_N was calculated from the difference between the measured creatinine value and the mean value for survivors, and dividing this difference by the standard deviation of the creatinine level in the survivors. BUN_N was calculated in the same way.

An Acute Trauma Index (ATI) was developed as a means to characterize patient status at the time of admission to a hospital (6). The Acute Trauma Index, like CHOP, is a Euclidean distance. It is based on admission values of systolic blood pressure (P), hematocrit (H), arterial pH (A), and prothrombin time (T), all of which respond soon after trauma. It has the form:

$$\text{Acute Trauma Index} = \sqrt{\left(\frac{P-127}{21.0}\right)^2 + \left(\frac{H-36.9}{5.96}\right)^2 + \left(\frac{A-7.46}{0.065}\right)^2 + \left(\frac{T-13.0}{2.0}\right)^2}.$$

The Shock Index (SI) uses systolic blood pressure (P), hematocrit (H), and arterial pH. It was derived from retrospective

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admission data in 1973 at MIEM. It gives higher weights to shock states (low systolic blood pressure and low hematocrit) and acidotic (low arterial pH) states than to hypertensive and alkalotic states as was reflected by the data on survivors and deaths.

Letting $x_1 = \frac{P-127}{21}$, $x_2 = \frac{H-37.0}{6.0}$, $x_3 = \frac{A-7.46}{0.065}$, and

$$y_1 = \begin{cases} 2|x_1| + 4 & \text{if } x_1 < -2 \\ |x_1|^3 & \text{if } -2 \leq x_1 < 0 \\ 2/3 x_1 & \text{if } x_1 > 0 \end{cases}; \quad y_2 = \begin{cases} 2|x_2| & \text{if } x_2 \leq 0 \\ x_2 & \text{if } x_2 > 0 \end{cases};$$

$$y_3 = \begin{cases} 2|x_3| & \text{if } x_3 \leq 0 \\ x_3 & \text{if } x_3 > 0 \end{cases}$$

The Shock Index is: $SI = y_1 + y_2 + y_3$

The Shock Index appears to be more sensitive than the ATI, in differentiating between patients who are seriously injured and those who are not.

The Blunt Anatomical Index (BAI) was originally developed (7) by reviewing the records of all trauma patients admitted to MIEM over a three year period. Upon death or discharge, a detailed diagnosis was provided by the attending physician and coded according to the Hospital Adaptation of the International Classification for Disease (H-ICDA) system. The coding was validated against the medical record diagnosis and autopsy reports where available. Patients injured by weapons and those without injuries in the H-ICDA code range of 800.0 to 959.9 were excluded. A group of 2135 patients were thus identified and a random sample of 1884 patients were chosen to develop the BAI and the remaining 251 were to be used to test the BAI.

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Using the group of 1884 patients, a computed "conditional" probability of survival (P_c) and an "effective" probability of survival (P_e) were developed for each injury code. The P_c is the proportion of survivors associated with each injury code. This reflects the survival associated with a given injury in the presence of other injuries. The conditional probabilities were used to rank the severity of the injury codes. This ranking was used to compute an "effective probability of survival", P_e , for each injury code. The P_e for a given injury code is the proportion of survivors in the subset of patients for whom the injury is the most severe injury sustained, the severity ranking being established by the P_c 's.

The effective probabilities were tested by comparing actual mortality rates in randomly generated groups with expected mortality rates as computed from the P_e 's.

A Triage Index has been developed (8) which is an objective, non-instrumental clinical evaluative device for use by physicians, nurses or paramedics at the initial encounter between the trauma victim and EMS system resources (pre-hospital or emergency department) to identify patients requiring hospitalization and at risk of dying. The index consists of 10 clinical variables: pulse rate and strength, capillary refill, lip color, respiratory rate and expansion, eye opening, verbal response and motor response, pupillary size and response (to light). Each parameter was evaluated in approximately 1200 patients in three hospital emergency departments in Maryland and Washington, DC to determine their separate and combined ability to predict outcome status.

A new anatomical injury coding system called PEBL, has been developed jointly by personnel from the Biophysics Branch of CSL, and clinicians from MIEM (9).

A basic requirement for PEBL was that it include sufficient detail to discriminate traumatic effects which differ with respect to location, size, mortality, morbidity, and treatment.

RESULTS AND APPLICATIONS

Mortality correlations are available for all of the indices (10,11,12) individually and for combined CHOP and Respiratory Indices, for combined Acute Trauma and Blunt Anatomical Indices, and for combined Triage and Shock Indices.

In Table I we give the PER values for the Indices. The values of P (the a priori probability of death) vary because the

TABLE I

PER Values for the Indices

	<u>P</u>	<u>E</u>	<u>R</u>
CHOP Index (CI)	.17	.16	.57
Respiratory Index (RI)	.34	.23	.51
Renal Index (REI)	.21	.18	.55
Combined CI and RI	.34	.33	.73
Acute Trauma Index (ATI)	.14	.10	.42
	.24	.26	.72
	.33	.23	.52
	.068	.074	.58
Shock Index (SI)	.33	.21	.48
	.068	.073	.58
Triage Index (TI)	.33	.33	.76
	.067	.081	.65
Combined CI and RI	.34	.33	.73
Combined ATI and BAI	.14	.22	.73
	.28	.28	.70
	.35	.40	.89
	.067	.093	.75

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results are obtained from several centers and in some instances for select populations (such as intubated patients only in the case of the Respiratory Index).

All of the indices are currently being used in various applications by researchers and clinicians at the MIEM, Washington Hospital Center, Monmouth Medical Center and hospitals in Canada, California, Colorado, Virginia, Pennsylvania, and Maryland.

The applications include patient triage, prognosis (at the time of hospital admission and throughout the patient stay) and tracking; initiation, assessment and communication of therapies; and general evaluation of care.

At the MIEM, the CHOP Index is used as a general predictor of survival for referral patients and for direct admission patients after the first 24 hours (10). A decision rule, based on the CHOP Index, which predicts death or survival, resulted in a misclassification rate of less than 10% for 650 patients in the Unit for more than one day. The misclassifications can be reduced by several percent by comparing the variables which contributes to a large index value to a table of "critical states".

It was also established (3) that the index frequently allows a downward trend to be identified several days before it becomes clinically recognizable.

Results from using Respiratory Index in a study group of 177 consecutive intubated patients showed that a RI of 0.1-0.37 was normal, a value of 2 or greater was an indication for intubation and a value of 6 or above was associated with a .12 probability of survival (4). The RI reflects the presence of pulmonary shunting in a variety of circumstances including atelectasis, pulmonary contusion, or pulmonary emboli.

A nomogram was designed which simplifies the computation of the index, allows one to follow the course of a patient with respiratory problems, and provides a guide for oxygen therapy (4) and for initiation for extracorporeal circulation therapy (13).

Respiratory failure has in the past been responsible for as many as one-third of the deaths in surgical Intensive Care Units. Respiratory Distress Syndrome of trauma will occur as an early complication in some 30% of victims of major blunt trauma with a mortality of up to 50% if not recognized early and aggressively managed. Without such sophisticated assessment as is available in

major centers, many physicians find difficulty in assessing the severity of respiratory problems. In addition, there is the added problem of following the patient's progress. We believe that the Respiratory Index and its associated probability of death chart and nomogram provide the physician with a simple and helpful guide.

A second analysis of the same 177 intubated patients was undertaken to combine the CHOP and Respiratory Indices (11). The overall mortality in the group of patients was 34%. When the indices were combined, it was found that a CHOP Index greater than 5 and a Respiratory Index greater than 6 was associated with a 94% mortality as compared to a 10% mortality when the CHOP Index was less than 5 and the Respiratory Index less than 6.

Our analysis (5) of renal variables and the Renal Index showed that Creatinine levels about 4.0 mg per 100 ml, a BUN over 80.0 mg per 100 ml, and a Renal Index over 3 are all rare in patients who survive trauma. Data for those patients who did have one of the criteria just mentioned were further analyzed to identify which first reached the "critical level". In the majority of cases the sensitive indicator was a Renal Index of 3.

Although acute renal failure after surgery or trauma is recognized as a grave complication, it too seldom provokes the urgent therapeutic response required. The therapeutic approach to acute renal failure in major trauma must be clearly distinguished from that in chronic renal failure where the traditional approach is appropriate. Multiple major trauma is frequently accompanied by hemorrhagic shock, requiring massive blood transfusion under circumstances which sometimes do not allow time for complete cross-matching. Crushed muscle, hematoma formation, and jaundice are commonly components of the primary complicating clinical syndrome. Under aggressive resuscitation, with massive colloid infusion, and the early promotion of diuresis, many patients exhibit only slight or transient impairment of renal function. Once renal failure is established, however, the prognosis is poor, despite full supportive treatment. We believe this accounts for the higher mortality rate in referred patients with an index greater than 2.0.

To reiterate, the results indicated that survival is unlikely when a patient's renal failure deteriorates to the levels earlier defined (e.g., Renal Index > 3), and that aggressive therapy must be directed at preventing deterioration to this level.

The Acute Trauma Index, Triage Index, Blunt Anatomical Index, and the Shock Index were developed to characterize patient status on

arrival at a hospital and are currently in use in several HEW studies focusing on triage and evaluation of patient care. The indices have been used (individually and in various combinations) to predict outcome, prospectively, for over 1,600 patients with excellent results (12, 14). The Triage Index has been surprisingly good considering that all of its data elements can be obtained easily and readily in both prehospital and hospital situations without resorting to invasive techniques.

Several of the indices have been incorporated (15, 16) into clinical algorithms (medical decision trees) for resuscitation of the critically injured patient.

A methodology for medical assessment of soft body armor (17) included correlations of lung damage in goats and humans using the Respiratory Index.

The PEBL Code (9) is part of a new computer man methodology (18) for assessing wound severity and medical workload (19, 20). The methodology consists of simulating missile wounds in a computer man and characterizing the wounds using strings of PEBL codes and associated surgical procedures and medical tasks required for treatment. Also, in process is work which correlates PEBL code strings with mortality using similarly coded data on traumatic injuries from US Army and civilian data bases.

SUMMARY

In the stressful situation of the battleground, it is imperative that rapid evaluation and classification of casualties be made for treatment and evacuation. Trauma indices provide the Army with such a device. For this reason, the work described herein is of importance.

We believe that the Triage Index and Shock Index could be part of a triage rationale for use by military aidmen and clinicians. Also, all of the indices could be applied during a military conflict as a basis for patient prognosis, tracking, and initiation and assessment of therapies.

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