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Application of a New Resource-Constrained Triage Method to Military-Age Victims

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ABSTRACT Objective: Evaluate the resource-constrained, evidence-based, and outcome-driven Sacco Triage method (STM) for military-age victims of blunt, penetrating, and blast overpressure-like trauma. Methods: STM is based on a mathematical model of resource-constrained triage. Its objective is to maximize expected survivors given constraints on transport and treatment resources. STM uses estimates of time-dependent victim survival probabilities and expected deteriorations. A respiration, pulse, and best motor response (RPM) score predicts survivability. Logistic function-generated survival probability estimates from 99,369 military-age victims were assessed using calibration and discrimination statistics. The consensus building Delphi method was used to provide aggregate expert opinion on victim deterioration rates. The models were solved using linear programming. Rule-based (not requiring software) protocols were determined using a greedy algorithm for Iraqi combat scenarios, and simulations enabled comparison of STM to the widely known Simple Triage and Rapid Treatment (START) method. Results: RPM was an accurate predictor of survival probability, equivalent to the Revised Trauma Score and exceeding the Injury Severity Score. In 18 simulations, STM and STM rule-based protocols increased survivorship over START from 20% to an 18-fold increase. Conclusions: STM offers lifesaving and operational advantages for military-age victims of blunt, penetrating, and blast overpressure-like trauma.

INTRODUCTION

The Sacco Triage method (STM)[1,2] is an evidence-based, outcome-driven method that maximizes expected survivors in consideration of the timing and availability of resources. It offers considerable lifesaving opportunities as compared to existing, nonevidenced-based triage methods. This article applies STM to military-age patients.

BACKGROUND

Triage is the assigning of treatment and evacuation priorities to patients. It was introduced during the Napoleonic Wars.[3] Current methods have their origins in the early 1980s and used simple sorting. The most widely used is Simple Triage and Rapid Treatment (START)[4] which, after separating the ambulatory and expectants, uses three physiological screens to sort victims into "immediates" and "delayeds." Patients are grouped by category, and immediates are transported first followed by delayeds. The military versions, including MIDE (minimal, immediate, delayed, and expectant) and the Pentagon Mass Casualty project (Mascal), are fundamentally the same as START.[5,6] These methods have the unmeasurable goal of "doing the greatest good for the greatest number." The START method is not evidence based, does not consider resources, and has been shown to be scientifically and operationally flawed.[7] General P. K. Carlton, former USAF Surgeon General, said of MIDE: "I felt it was not reproducible, not scalable, had no scientific basis, and did not lend itself to computer applications."[8] David Cone adds: "Surprisingly, there has been very little research validating or even evaluating these systems."[9]

STM, conceived shortly after 9/11, is the first evidence-based, outcome-driven triage method for resource-constrained triage.[1,2] It has been applied for blunt-injured victims,[1] penetrating-injured victims,[2] and blast overpressure-like victims[10] and adapted to account for age variations (Sacco W, Romig L, Cooper A, et al: Application of Patient Age-Dependent STM (A Resource Constrained Triage Method) to Blunt Injured Victims. 2009. unpublished.).

STM prescribes computing physiological scores to predict each patient's survival probability and expected deterioration and making triage decisions that maximize the number of expected survivors in consideration of those scores and the timing and availability of transport and treatment resources. The scores for blunt, penetrating, and blast overpressure-like injuries are based on coded values for respirations, pulse, and best motor response. Victims are organized by score. STM uses the distribution of patient scores, the associated survival probability and deterioration rates, and resource information to determine an optimal triage strategy. The resulting strategy is an assignment of patients in priority order by transport mode to specific treatment facilities.

METHODS

Resource-constrained triage can be formulated mathematically as an easily solvable linear programming problem. Patient scores are correlated to survival probability using logistic regression for a military-age population and validated through measures of discrimination and calibration. Deterioration estimates are determined through the Delphi method from a panel of experts. A greedy algorithm is used to determine rule-based models of STM, and simulations enable outcome comparisons of STM and START.

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Mathematical Formulation of Resource-Constrained Triage

We formulate resource-constrained triage mathematically. The goal is to maximize expected survivors, subject to constraints on transport and treatment resources. For simplicity, we present a formulation that does not include treatment resources explicitly. Let

$V_{s,t}$ = number of victims treated in time period t whose original (first assessment)

SCORE is s. (Note: SCORE is generic and used here to represent any scoring metric that can be used to predict survival probability) P_s (t) = the survival probability of victims with original SCORE s treated in time period t. n_s = number of victims with original SCORE s. R_t = maximum number of victims transported in time period t. s = 0, 1, …, S; t = 1, 2, …, k .

The objective is to maximize expected survivors:

(1) $\text{Max}\ \{[P_0(1)V_{0,1} + P_1(1)V_{1,1} + \cdots + P_{12}(1)V_{12,1}] + [P_0(2)V_{0,2} + P_1(2)V_{1,2} + \cdots + P_{12}(2)V_{12,2}] + \cdots\cdot + [P_0(k)V_{0,k} + P_1(k)V_{1,k} + \cdots + P_{12}(k)V_{S,k}]\}$, subject to constraints on transport resources (A) and victims at the scene (B):

$$V_{0,1} + V_{1,1} + \cdots + V_{12,1} \le R_1$$

$$V_{0,2} + V_{1,2} + \cdots + V_{12,2} \le R_2$$

(A) ....

$$V_{0,k} + V_{1,k} + \cdots + V_{12,k} \le R_k, \text{ and}$$

$$V_{0,1} + V_{0,2} + \cdots + V_{0,k} = n_0$$

$$V_{1,1} + V_{1,2} + \cdots + V_{1,k} = n_1$$

(B) ....

$$V_{S,1} + V_{S,2} + \cdots + V_{S,k} = n_S.$$

Formulation Fits Linear Programming Structure; Can be Solved Efficiently

This model is a linear programming formulation[11] of resource-constrained triage. Problems that fit a linear programming structure can be solved efficiently, even for large-scale problems, by the simplex method[11] using commercial software. Linear programming and the simplex method are well-documented methods for solving large-scale optimization problems that have linear objective functions and linear constraints.

The output of the linear program is the triage strategy. It specifies the number of victims with each RPM value and in priority order to be transported by mode and/or treated such that the expected number of survivors is maximized, given limitations on resources. The simplex method provides solutions in seconds, and can be recomputed in response to scene and resource changes. Operational and mathematical extensions allow for patients to be assigned by mode of transport to specific treatment facilities.

The linear programming formulation above is generic. SCORE can be any measure that can characterize victim severity and estimate survival probability. It may depend on the type of trauma/toxic insult (e.g., blunt, penetrating, blast, burn, chemical).

Physiological Score Used to Predict Survival Probability

STM requires an estimation of survival probability for each casualty. The SCORE used for blunt-injured, penetrating-injured, and blast overpressure-injured casualties is RPM,[1,2,12–14] which is computed as the sum of coded values for respiratory rate (RR), pulse rate (PR), and best motor response (BMR) (see Table I). A patient with no physiological response would score a “0,” whereas a patient with physiological responses within normal ranges would score a 4 in all measures. Thus RPM takes on integer values from 0 to 12. Respiratory rate is measured in breaths/minute and pulse is measured in beats/minute. Best motor response assesses the patient’s ability to respond to stimuli:

- Obeys command: The victim comprehends and complies with a verbal command such as “raise your hand.”

If the victim cannot comply, a painful stimulus (e.g., a nail bed pinch or sternal rub) is applied.

- Localizes pain: The victim reaches or tries to remove the source of pain.
- Withdraws: Flexion of elbow, with rapid movement and no muscle stiffness. The arm is drawn away from the trunk.
- Flexion: Elbow flexes slowly, accompanied by stiffness. Forearm and hand remain against the body (decorticate posturing).
- Extension: Legs and arms extend, accompanied by stiffness. There is internal rotation of shoulder and forearm (decerebrate posturing).
- None: No response.

Logistic Regression Determines RPM-Based Survival Probability Estimates

The STM formulation was applied separately to blunt, penetrating, and blast overpressure-like injured patients to obtain models for scene and Emergency Department (ED) applications.

TABLE I. RPM Scoring Model

Coded Values	0	1	2	3	4
Respiratory Rate	0	1–9	36+	25–35	10–24
Pulse Rate	0	1–40	41–60	121+	61–120
Best Motor Response	None	Extends/Flexes From Pain	Withdraws From Pain	Localizes Pain	Obeys Commands

The applications use survival probability estimates obtained from retrospective analyses of patient data from trauma centers participating in the Pennsylvania Trauma Outcome Study (PTOS). The PTOS is a statewide trauma registry containing demographic information, nature of injury, external cause of injury, severity of injury, and hospital outcomes for patients treated at Pennsylvania's 26 accredited level I and II trauma centers.

Patients represented in the PTOS database include in-hospital deaths from trauma and survivors admitted to a hospital for at least 72 hours or admitted to the intensive care unit during their hospital stay or transferred into or out of a trauma center. The PTOS database was stratified by trauma type. For penetrating trauma, we used patients with gun shot wounds. For blunt trauma we used patients with injuries resulting from crushes, motor vehicle crashes, and falls. For blast overpressure-like trauma we used patients with blast-like injuries (BLI) within the PTOS database. Abbreviated Injury Scale (AIS) codes were specified to identify patients with at least one blast-like injury. To isolate patients with BLI as the dominant trauma, we excluded patients who also had serious (AIS >2) non-BLI injuries.

Survival probability models were determined for military-age patients for each type of trauma. All models used RPM values from the PTOS database, scene values for scene models, and ED admission values for ED models.

We used RPM values for patients whose age distribution matched those for U.S. combat casualties in the Iraqi conflict. The military age distribution was based on U.S. deaths in Iraq as of March 17, 2005. Of the deaths of patients 40 years or younger, about 76% were age 18–30. Our rationale for selecting patients from the PTOS database was to maximize the number of patients age 18–40 selected, subject to the constraint that 76% are age 18–30.

For scene models, we included only nontransfer patients with complete RPM values exclusive of patients intubated before assessment of respiratory rate or best motor response. Intubation precludes accurate respiratory or neurologic assessments and is rarely performed in mass casualty events. For the ED models we included only nontransfer patients with complete ED admission RPM values exclusive of patients intubated at ED arrival.

For each model, study patients were divided into a design set and test set. The design set included every other survivor and every other nonsurvivor. The test set included remaining patients. Logistic function coefficients were derived on the design set, and validated on the test set. The logistic function has the form:

$P_s = 1/(1 + e^{-w})$, where P_s is the survival probability estimate.

$w = w_0 + (w_1 \times \text{RPM})$.

Logistic function-generated survival probability estimates were determined using SAS version 8 for incident scene RPM values. Logistic regression coefficients (w_0, w_1), obtained from the design set, were used to estimate survival probabilities in the test set. The logistic function predictive performance was assessed by computing concordance[15] (a discrimination measure) and a normalized Hosmer-Lemeshow (HL) statistic[16] (a calibration measure) and comparing them to the predictive performance of the Injury Severity Score (ISS) and Revised Trauma Score (RTS) on the same data set.

Discrimination, the ability of a scoring system to distinguish survivors and deaths, is often measured by concordance (*C*), which compares the survival probabilities of all pairs of survivors and nonsurvivors in the test set. A score of 1 is assigned if the survivor has a survival probability greater than that of the nonsurvivor. A score of 0.5 is assigned if the survivor and nonsurvivor have the same survival probabilities. A score of 0 is assigned otherwise. The concordance is the sum of these scores divided by the total number of comparisons. A concordance value of 0.5 indicates no predictive discrimination, and a value of 1.0 indicates perfect separation of survivors and nonsurvivors. The closer *C* is to 1.0, the better the discrimination value.

Calibration is the degree of agreement between actual and score-predicted survivors and deaths in various risk strata. Here, we use a standardized variant of the HL statistic as a measure of calibration. The HL statistic measures a logistic function's predictive calibration across the range of P_s. It is based on comparisons of the actual and expected numbers of survivors and deaths for all P_s deciles. Until recently, goodness-of-fit generally was declared "good" in trauma severity scoring literature if the HL statistic was less than 15.5. However, several researchers[17,18] have pointed out that the HL statistic becomes artificially inflated as the sample size increases, which makes statistical significance an inappropriate goal. For this reason we present both HL and normalized HL (NHL) (computed as the HL divided by the number of patients in the sample).

For the total set (combined design and test sets) we computed the logistic function weights, *C*, HL, NHL, and survival probability estimates for each RPM value. The survival probability estimates for the total set are used in the STM model.

Delphi Technique Used to Estimate Victim Deterioration

Change in survival probability estimates for victims who remain at the incident scene were obtained using the Delphi technique[1,2,19,20] which achieves consensus estimates among experts when empirical evidence is unavailable or insufficient.

The Delphi technique was used to obtain a consensus among 11 trauma care experts of estimates of changes in RPM values for victims presumed to receive little or no treatment while awaiting transportation to a higher level of care. Each expert provided estimates of scene RPM value changes in 30-minute increments over a 6-hour period and a rationale. The estimators were to presume that minimal care could be provided by emergency responders. For example, a victim may have his/her airway opened or receive a pressure bandage to control bleeding, but resources would not be available to provide continuous intravenous fluids or invasive therapeutic interventions. Estimates assume basic care while awaiting treatment at the ED.

Anonymous estimates and rationales for all estimators were shared, and a second round of estimates was requested. These estimates were used to compute median changes in RPM values (denoted as Delphi estimates) for successive time periods for each initial RPM value.

Greedy Algorithm Determines Rule-Based Combat Triage Protocols

Rule-based protocols are simple models that can be used to make combat triage decisions by corpsmen. The motivation is to provide easily implementable triage solutions in the absence of communications or technology. The rule-based methods have been shown to be optimal or near optimal in all cases. The triage rules are based on survival probabilities and expected deterioration, but are not necessarily optimal as the rules are prepared a priori and do not consider incident-specific severity distributions, or resource timing and availability. We used a "greedy algorithm" in this research (software simulations can also be used) to determine the rules. The victim ordering for a given time period is determined from ordering RPM deteriorations from largest to smallest, as measured by decreases in estimated probabilities during the time period. That is, the greater the deterioration, the earlier the RPM value appears in the sequence, unless the estimated survival probability has deteriorated to zero.

General Simulations Compare STM Military-Age Results to Previously Published Research

For comparison of the military-age models to the general population in previously published research, a set of general simulations are presented. Table II shows 3 patient distributions, each with 60 patients with RPM scores between 2 and 8, and each with a mix of immediates and delayeds. Simulations reflect three levels of resources. In resource scenario 1, we assume moderately limited resources sufficient to transport 20 patients per 30 minutes. In resource scenario 2, we assume a more resource-constrained environment and reduced transport rate of 10 victims per 30 minutes. In resource scenario 3, we assume severe resource limitations and a transport rate of 6 victims per 30 minutes. For ease of discussion we define each combination of patient distribution and resource scenario as a "set" in the Results section (e.g., set1.2 is patient distribution 1 under resource scenario 2).

Combat Models Defined for Iraqi Triage

Active Navy personnel suggested three combat triage transport scenarios—30-minute, 60-minute, and 90-minute transport—denoted Transport30, Transport60, and Transport90. We assume an incident size such that it would take 90 minutes to clear the scene of casualties. We also assume two ED models, reflecting a 30-minute or 60-minute wait for definitive care at the treatment facility, denoted as EDWait30 and EDWait60. We show the rule-based models for these cases.

TABLE II. Simulation Distributions of Patient Severity

Distribution	Number of patients	RPM Score	START Category
1	10 each 10 each	2, 3, 4 6, 7, 8	Immediates Delayeds
2	14 each 6 each	2, 3, 4 6, 7, 8	Immediates Delayeds
3	6 each 14 each	2, 3, 4 6, 7, 8	Immediates Delayeds

RESULTS

RPM Accurately Predicts Survival

RPM has been shown to be a good predictor of survival probability for the blunt, penetrating, and blast overpressure-like scene models and for the blunt and penetrating ED models.

Sample Sizes

Table III shows the sample sizes for scene and ED models, respectively, for blunt, penetrating, and blast overpressure-like trauma. As shown, the samples are largest for blunt trauma. The table shows the numbers of survivors and deaths.

Logistic Coefficients

Table IV shows logistic coefficients for the scene and ED models, respectively. Note that the coefficients for the design sets and total sets for all models are similar. These indicate the coefficients determined for the design sets accurately extend to the total sets.

Discrimination and Calibration Statistics

Concordance, HL, and NHL statistics for the scene and ED models are shown in Table V. The concordances and NHLs

TABLE III. Sample Sizes

	Sample Size	Survivors	Deaths
Scene Model			
Blunt	23,895	22,838	1,057
Penetrating	4,156	3,461	695
Blast Overpressure	3,326	3,168	158
ED Model			
Blunt	50,349	49,639	710
Penetrating	14,088	12,892	1,196
Blast Overpressure	3,555	3,484	71

TABLE IV. Logistic Coefficients

	Design Set		Total Set	
	w_0	w_1	w_0	w_1
Scene Model				
Blunt	−3.68	0.74	−3.38	0.72
Penetrating	−4.67	0.68	−4.70	0.70
Blast Overpressure	−3.19	0.64	−3.20	0.65
ED Model				
Blunt	−2.88	0.72	−2.98	0.73
Penetrating	−4.06	0.70	−3.87	0.68
Blast Overpressure	−3.07	0.69	−3.55	0.73

signify that all models are good predictors of survival probability estimates. For the scene model, the test set *C* values range from 0.91 to 0.94, whereas test set NHL values range from 0.0031 to 0.019. For comparison, test set *C* values range from 0.84 to 0.95 and test set NHL values range from 0.0011 to 0.0126 (smaller is better here) for such widely used physiologic scores as the trauma score[21] and revised trauma score[22] and such anatomic scores as injury severity score,[23] Modified Anatomic Profile (mAP),[17] and the International Classification Injury Severity Score (ICISS).[17] Results for the ED model are also favorable in both statistics. As shown, *C* values for the test set range from 0.88 to 0.94 whereas NHL values range from 0.00060 to 0.0044. These compare favorably to the *C*-value range of 0.84 to 0.95 and NHLvalue range from 0.0010 to 0.0126 for the trauma score, revised trauma score, injury severity score, mAP, and ICISS.

Survival Probability Estimates

The scene and ED model survival probability estimates are provided in Table VI. Blunt trauma generally has the greatest survival probability for each RPM value, with blast overpressure-like trauma tracking closely. Penetrating trauma declines significantly in comparison as RPM values drop.

Deterioration Models by Type of Trauma

Table VII shows Delphi estimates of deterioration, as indicated by the change over time of the RPM score, for scene values for penetrating trauma. For example, the Delphi consensus of our expert panel indicated a patient with blunt trauma and an initial RPM score of 8 would remain an 8 for two time periods, and then deteriorate to a 7 for two time periods, and then drop 1 RPM point in each half hour until they expired (if not treated). The deterioration is not linear in survival probability. Victims with RPMs greater than 8 deteriorate slowly, as one might expect, and all others deteriorate more quickly. Table VIII shows the Delphi estimates of changes in RPM values for patients with penetrating injuries at the ED of a combat hospital presumed to provide modest treatment while awaiting definitive care.

Applications use an estimated (i.e., smoothed) version of the deterioration models as a more realistic representation of deterioration. (Note: Please contact the authors for Delphi Tables for blunt and blast trauma for scene and ED models).

TABLE V. Discrimination and Calibration Statistics

	Scene Model			ED Model		
	C	HL	NHL	*C*	HL	NHL
Blunt						
Design Set	0.94	16	0.0013	0.92	18	0.00071
Test Set	0.94	37	0.0031	0.92	15	0.00060
Total Set	0.94	26	0.0011	0.92	28	0.00058
Penetrating						
Design Set	0.95	30	0.015	0.94	24	0.0034
Test Set	0.94	39	0.019	0.94	31	0.0044
Total Set	0.94	66	0.016	0.94	40	0.0029
Blast Overpressure						
Design Set	0.88	20	0.012	0.87	7.6	0.0043
Test Set	0.91	14	0.0084	0.88	6.7	0.0038
Total Set	0.89	20	0.0060	0.85	6.7	0.0019

TABLE VI. Survival Probability Estimates

	Survival Probability Estimates			Survival Probability Estimates		
RPM Value	Blunt	Pen	Blast	Blunt	Pen	Blast
0	0.033	0.0090	0.039	0.048	0.020	0.028
1	0.065	0.018	0.073	0.096	0.039	0.057
2	0.12	0.036	0.13	0.18	0.075	0.11
3	0.23	0.069	0.22	0.31	0.14	0.21
4	0.37	0.13	0.36	0.49	0.24	0.35
5	0.55	0.23	0.51	0.66	0.38	0.53
6	0.71	0.37	0.67	0.80	0.55	0.70
7	0.84	0.54	0.80	0.89	0.71	0.83
8	0.91	0.71	0.88	0.95	0.83	0.91
9	0.96	0.83	0.93	0.97	0.90	0.96
10	0.978	0.91	0.96	0.987	0.95	0.978
11	0.988	0.95	0.98	0.994	0.97	0.989
12	0.995	0.97	0.99	0.997	0.99	0.995

Pen, penetrating.

Rule-Based Combat Triage Protocols

Rule-based strategies were determined during each time period and are presented for the Iraqi combat models in Tables IX and X, for the scene and ED models, respectively. For example, if travel time to definitive care for penetrating-injured victims is estimated to be 90 minutes (i.e., transport90), the top priorities for transport during the first 30 minutes are patients with scores of 7, 6, and 5. If the scene has not been cleared by the third 30-minute time interval, the top priority patients are those with scores of 8 and 9. Priorities change over time reflecting the changing survival probability of those left untreated. Table X shows similar rule-based strategies for patients awaiting care at the ED. If wait time is estimated to be 30 minutes (i.e., EDWait30), blunt-injured patients with scores of 4 and below receive top priority initially, but if patients are still awaiting care after 30 minutes, patients with scores below 4 are now low priority as it is expected that their deterioration will make their survival unlikely or too costly in resources.

TABLE VII. DELPHI Estimates of RPM Values in 30-Minute Time Intervals for Penetrating Scene Deteriorations (For Healthy Military-Age Victims)

	Time Intervals											
Initial RPM	1	2	3	4	5	6	7	8	9	10	11	12
12	12	12	12	12	12	12	11	11	10	10	9	9
11	11	11	11	11	10	10	10	10	9	9	9	8
10	10	10	9	9	8	8	8	8	7	7	6	6
9	9	9	8	8	7	6	5	4	3	2	1	1
8	8	8	7	7	6	5	4	3	2	1	1	1
7	5	4	3	2	1	0	0	0	0	0	0	0
6	4	3	2	1	0	0	0	0	0	0	0	0
5	3	2	1	0	0	0	0	0	0	0	0	0
4	2	1	0	0	0	0	0	0	0	0	0	0
3	2	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE VIII. DELPHI Estimates of RPM Values in 30-Minute Time Intervals for Penetrating ED Admission (For Healthy Military-Age Victims)

	Time Intervals											
Initial RPM	1	2	3	4	5	6	7	8	9	10	11	12
12	12	12	12	12	12	12	11	11	11	10	10	9
11	11	11	11	11	11	10	10	10	9	9	9	8
10	10	10	9	9	9	9	8	8	8	7	7	6
9	9	9	8	8	7	7	6	5	4	3	2	1
8	8	8	7	7	6	6	5	4	3	2	1	1
7	5	4	3	2	1	0	0	0	0	0	0	0
6	4	3	2	1	0	0	0	0	0	0	0	0
5	3	2	1	0	0	0	0	0	0	0	0	0
4	2	1	0	0	0	0	0	0	0	0	0	0
3	2	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE IX. Scene Triage Rules Under 3 Combat Scenarios

	Scenario 1: 60-Min Travel	Scenario 2: 90-Min Travel	Scenario 3: 120-Min Travel
Penetrating			
First 30 minutes	7–3 8–12 2 1	7–5 8–12 4–1	8–12 7–1
Second 30 minutes	8–10 7 5 4 11 12 3–1	7 6 8–12 5–1	9 8 10–12 7–1
Third 30 minutes	7–5 8–12 4–1	9 8 10–12 7–1	9 8 10–12 7–1
Blunt			
First 30 minutes	6 5 4 3 7–12 2 1	6 5 7–12 4–1	7 6 8–12 5–1
Second 30 minutes	7 6 5 9 4 8 10–12 3	7 8 11 6 9 10 12 5–1	8 9 7 10–12 6–1
Third 30 minutes	7 6 8 5 9 10–12 4–1	8 7 9–12 6–1	9 8 7 10–12 6–1

The rules include a representation of deterioration, and assume patients are not rescored. If circumstances allow rescoring of all patients, different rules would apply. On the basis of discussions with active military doctors returning from Iraq, it would be routine to rescore patients while awaiting treatment at the ED.

TABLE X. ED Triage Rules Under 2 Combat Scenarios

	Scenario 1: 30-Min Wait	Scenario 2: 60-Min Wait
Penetrating		
First 30 minutes	7–1 8–12	7 6 5 4 8–12 3–1
Second 30 minutes	7–1 8–12	7 8 6 9–12 5–1
Third 30 minutes	8 7 9 6 10 11 12 4–1	8–12 7–1
Fourth 30 minutes	7 6 8–12 5–1	9 8 10–12 7–1
Fifth 30 minutes	8 9 7 10–12 6–1	9 8 10–12 7–1
Sixth 30 minutes	7–12 6–1	10 9 11 12 8–1
Blunt		
First 30 minutes	4 2 3 1 5–12	4 3 2 5–12 1
Second 30 minutes	4 5–12 3–1	5 7 6 8–12 4–1
Third 30 minutes	5–12 4–1	6 5 7–12 4–1
Fourth 30 minutes	5–12 4–1	7 6 5 8–12 4–1
Fifth 30 minutes	6 7 5 8–12 4–1	7 6 5 8–12 4–1
Sixth 30 minutes	6 5 7–12 4–1	8–12 7–1

Simulation Results Show Lifesaving Potential

As shown in Tables XI and XII STM and STM rules saved considerably more lives in all simulations. Note that because START does not provide an exact triage order, the results are presented as a range covering all possible orderings of patients within the protocol of taking immediates first. Observations of START in exercises indicate that the expected result is typically near the middle of the range. The "maximum expected survivors" shows the number of expected survivors if resources were sufficient to treat every patient immediately. This provides an upper bound on expected survivors for each simulation and a context to assess triage performance.

The STM optimal and STM rules dominate START in all 18 simulations, resulting in projected lifesavings ranging from about 20% to more than 300%. In lives, the number of additional military and Iraqi civilians saved in these simulations of 60 patients ranges from 3 to 12.

In the scene model in simulation sets 1.1 to 1.3, with victims distributed uniformly between immediate and delayeds, the number of projected survivors increased by 27% to 43% with STM over START in all resource scenarios even if START randomly achieved the maximum possible survivors. In sets 2.1 to 2.3, with more seriously injured patients, STM increased projected survivors by 43% to 87% as compared to START's

TABLE XI. Simulation Results for Scene Model, Penetrating Trauma

Set	Maximum Expected Survivors[a]	Expected Survivors STM	Expected Survivors START Min–Max	% Gain in STM Projected Survivorship as Compared to:		Rule-Based Expected Survivors
				START Max	START Min	
1.1	18.55	16.97	10.50–12.17	39	62	16.97
1.2	13.01	11.54	7.11–8.09	43	62	11.54
1.3	24.09	21.22	14.62–16.66	27	45	21.22
2.1	18.55	13.89	5.23–7.89	76	166	13.89
2.2	13.01	9.69	3.26–5.18	87	197	9.53
2.3	24.09	16.94	8.30–11.83	43	104	16.65
3.1	18.55	11.20	0.75–4.28	162	1393	11.09
3.2	13.01	8.36	0.42–1.58	429	1890	8.36
3.3	24.09	13.51	1.39–8.39	61	872	13.18

[a] Maximum expected survivors is the number of expected survivors when there are unlimited resources and all patients were immediately treated.

TABLE XII. Simulation Results for ED Model, Penetrating Trauma

Set	Maximum Expected Survivors[a]	Expected Survivors STM	Expected Survivors START Min–Max	% Gain in STM Projected Survivorship as Compared to:		Rule-Based Expected Survivors
				START Max	START Min	
1.1	25.45	22.40	15.00–17.20	30	49	22.40
1.2	18.91	15.96	10.69–12.30	30	49	15.96
1.3	31.99	27.68	20.47–22.73	22	35	27.68
2.1	25.45	18.00	8.70–11.85	52	107	18.00
2.2	18.91	12.88	5.43–8.07	60	137	12.88
2.3	31.99	21.72	13.20–16.17	34	65	21.72
3.1	25.45	14.49	2.80–7.67	89	418	13.68
3.2	18.91	10.80	1.49–4.45	143	625	10.80
3.3	31.99	17.57	5.06–11.824	49	247	17.57

[a] Maximum expected survivors is the number of expected survivors when there are unlimited resources and all patients were immediately treated.

maximum outcome. The lifesavings increases under START's worst case performance ranges between 45% to 200%. In sets 3.1 to 3.3, dominated by less severe patients, the projected survivors with STM ranges from 61% to 429% as compared to START's maximum performance and increases more than 18-fold in comparison to START's worst case performance. START's use of scarce resources on patients with little chance of survival is at the expense of more savable patients.

The STM rule-based protocol attained an optimal or near optimal result in all simulations.

DISCUSSION

STM was shown to have potential to significantly increase lives saved in resource-constrained combat triage. A simple physiological score based on pulse, respirations, and best motor response was shown to be an accurate predictor of survival probability for a military-age population for blunt, penetrating, and blast overpressure-like injuries.

Adaptation of STM for Use for Combat Triage

It has been suggested that the primary combat application for STM is at treatment facilities. Combat patient destination tends to be predetermined on the basis of incident location, and scene triage is minimal as the majority of combat patients that die do so within minutes of the insult, whereas wounded soldiers are rapidly moved to treatment and are not typically staged. Triage at the ED is often performed by the surgeons themselves, and in discussions with combat trauma surgeons including the deputy force surgeon, Navy expeditionary combat command, and the commander of the Navy medicine office of Homeland Security, it was suggested that STM be considered primarily for ED triage and that it offers the advantage of being an "objective method of triage."

Retrospective Data Review Illustrates Problems with Current Military Triage Protocols

A retrospective analysis of the Navy/Marine Corps Combat Trauma Registry, conducted independently of the ONR research, illustrates how current protocols do not provide the patient differentiation needed to make effective triage decisions. Of 1,266 patients with complete RPM values and outcome information who had normal physiology (i.e., an RPM score of 12):

- 381 (28%) were tagged minimal.
- 343 (25%) were tagged delayed.
- 303 (22%) were tagged immediate.
- 334 (25%) were not tagged.

Field Implementation

Combat implementation of STM in Iraq or Afghanistan would enable lifesaving opportunities, and provide combat casualty data for feedback to the model. Implementation would require training of corpsmen and other prehospital and ED staff to compute the RPM score, utilize rule-based triage protocols, and collect RPM data.

Continuing Research

Since STM is evidence based, it invites continuing research. Research is underway to develop a score that could be used to predict survival probability and deterioration for chemical trauma and to develop combat protocols for Canadian military use in Afghanistan. While initial research indicates the impact of certain chemical agents could be measured by RPM, a modified scoring metric might be needed and new triage rules created.

Comment on Simulations

Sixty patient simulations were used in this study to enable the reader to compare results to previous published research. Lifesaving potential has been seen at various levels of patient casualties, and results herein extend to smaller and larger numbers of casualties.

CONCLUSIONS

STM was shown to extend to military-age personnel for blunt, penetrating, and blast overpressure-like trauma. The RPM-based scoring measure accurately predicts survival probably as measured by calibration and discrimination statistics. Simulations show that STM has significant potential to increase combat casualty survivorship and further show that STM rule-based protocols achieve optimal or near-optimal solutions and would be adaptable for combat triage. Sample combat rule-based protocols were included herein for demonstration purposes, and deployment to Iraq and Afghanistan would require a more rigorous examination of combat operations to best enable corpsmen and combat hospital personnel to make evidence-based triage decisions without the need for communications or computing technology.

We believe STM will increase survivorship and is applicable to combat, terrorist incidents in homeland defense, and to civilian multiple and mass casualty incidents. It is appropriate for triage of patients with blunt, penetrating, and blast overpressure-like injuries. It supports simulations of casualty incidents to gauge the effectiveness of resource allocations and enables measureable training and exercises. Finally, this system provides for the collection and tracking of casualty data that can be fed back to continually improve the probability and deterioration models.

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APPENDIX A

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