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Validation of a Decision Support Tool for the Evaluation of Cardiac Arrest Victims

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Summary

Background: There is currently no well-accepted model for early and accurate prediction of neurologic and vital outcomes after cardiac arrest. Recent studies indicate that individuals with acute myocardial ischemia as the etiology for the arrest may benefit from early revascularization.

Hypothesis: This study was undertaken to examine whether the cardiac arrest score is valid for predicting outcomes upon arrival at the emergency department.

Methods: We previously developed a cardiac arrest score based on time to return of spontaneous circulation, initial systolic blood pressure, and level of neurologic alertness in 127 patients (derivation set). This score was prospectively applied to 62 patients with similar clinical profiles (validation set). Utility of the score was evaluated by the area under the receiver operator characteristic curves (C) for both sets. Consistency was measured by using the alpha statistic applied to the cumulative survival at each ascending level of the score.

Results: The derivation and validation sets were similar with respect to baseline characteristics and proportions at each level of score. The survival to discharge was 41.7 and 53.2% for the two sets, respectively. The value of C was 0.89 ± 0.03 and 0.93 ± 0.03 for neurologic recovery and 0.81 ± 0.04 and 0.92 ± 0.04 for survival to discharge in the two sets, respectively. The level of agreement between the sets across the levels of the score was 0.98 and 0.99 (both $p < 0.0001$) for the two outcomes.

Conclusions: The cardiac arrest score is a valid decision support tool in the evaluation of cardiac arrest victims. Patients with the most favorable scores may be considered for early angiography and revascularization if myocardial ischemia is the etiology of the arrest.

Key words: cardiac arrest, cardiopulmonary resuscitation, decision support, mortality, anoxic encephalopathy, Bayesian analysis, prognosis

Introduction

We have previously proposed a predictive scoring scheme for patients with witnessed cardiac arrest defined as the abrupt loss of consciousness within 1 h of the onset of symptoms in a person with or without preexisting heart disease and in whom the time and mode of death are unexpected.[1, 2] Accurate prediction of outcomes is critical since, in the United States, sudden death is a major public health problem with only 20–30% of cases reaching the emergency department to face a 70% in-hospital mortality.[3–5] Although some early markers have been proposed, their accuracy and utility in predicting outcome is debated.[6–9] Previous predictive schemes have utilized factors which were not known until several hours to days after presentation and are not in widespread clinical practice.[8]

In cardiac arrest survivors with acute myocardial infarction, aggressive early management including cardiac catheterization and coronary angioplasty has been shown to have favorable results in early and late morbidity and mortality.[10, 11] Our aim was to validate a scoring scheme that identifies patients who will survive and recover neurologically and, hence, may benefit from early aggressive treatment.

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Materials and Methods

The initial derivation set of patients has been described previously.[1,2] Briefly, we identified a retrospective cohort of 127 witnessed, out-of-hospital, cardiac arrest survivors who were successfully resuscitated and admitted to William Beaumont Hospital, a 929-bed tertiary care center, between January 1989 and January 1996. Using multivariate techniques, a prediction model was derived from variables that were available at the time of emergency department evaluation. Subsequently, we prospectively identified a validation set consisting of 62 patients with out-of-hospital cardiac arrest from January 1996 to April 1997. In all, 44 variables, determined from patient historical information and hospital course, were ascertained from the time of admission until the time of discharge. All deaths documented were in-hospital and prior to discharge. Neurologic survival was defined as absence of severe neurologic deficits by clinical examination at the time of discharge.

Cardiac Arrest Score

A score was devised using time to return of spontaneous circulation, systolic blood pressure on arrival at the emergency department, and initial neurologic evaluation.[12] The point system for the cardiac arrest score is given in Table I.

TABLE I Cardiac arrest scoring scheme

Component	Points
Initial systolic blood pressure	
< 90 mmHg	0
≥ 90 mmHg	1
Time to return of spontaneous circulation	
≥ 25 min	0
< 25 min	1
Initial neurologic assessment	
Comatose or simple reflexes only	0
Spontaneous limb movement only to fully alert and oriented	1
Maximum possible points	3

Statistical Analysis

Baseline characteristics are reported for both patient sets with means ± standard deviation or proportions with ANOVA or chi-square for comparison, as appropriate. Pearson correlation was used to evaluate the relationships between the cardiac arrest score and clinical outcomes in the derivation and validation sets. The cumulative proportions of outcomes for the ascending of levels achieved were treated as scales and subjected to the alpha agreement statistic to evaluate reliability of the cardiac arrest score. Bayesian analysis was used to evaluate the utility of the sudden death score in predicting outcomes. The pretest probabilities were obtained from the derivation set and post-test probabilities were calculated from the sudden death score as it applied to the validation set. Receiver operating characteristic (ROC) curves graphing the sensitivity (true positives) versus 1 − specificity (false positives) were used to evaluate the sudden death score levels (0,1,2,3) and their influence on post-test probabilities. Those curves were then compared with each other by evaluating the area under the ROC curve defined as C ± standard error. The standard of reference was considered to be the observed outcomes determined prospectively from the validation set.

Results

Baseline Characteristics

A comparison of baseline characteristics between the derivation and the validation cohorts is given in Table II. Of

TABLE II Baseline characteristics of the derivation and validation sets

Characteristic	Derivation set (n = 127)	Validation set (n = 62)	p Value
Female (%)	43 (33.9)	18 (29.0)	0.51
Male (%)	84 (66.1)	44 (71.0)	0.51
Mean age in years	68.6 ± 12.0	65.1 ± 13.7	0.10
History of prior cardiac arrest (%)	11 (8.7)	3 (4.8)	0.56
History of prior electrophysiologic study (%)	6 (4.7)	3 (4.8)	0.99
Prior MI by ECG (%)	50 (39.4)	22 (35.5)	0.61
History of prior bypass surgery (%)	0 (0)	1 (1.6)	0.30
History of prior coronary angioplasty (%)	3 (2.4)	4 (6.5)	0.22
History of heart failure (%)	23 (18.1)	10 (16.1)	0.74
Diabetes (%)	0 (0)	1 (1.6)	0.30
Hypertension (%)	64 (50.4)	30 (48.4)	0.80
Tobacco use (%)	40 (31.5)	25 (40.3)	0.23
Dyslipidemia (%)	23 (18.1)	6 (9.7)	0.13

Abbreviations: MI = myocardial infarction, ECG = electrocardiogram.

TABLE III Clinical factors available in the emergency department in 189 survivors of out-of-hospital cardiac arrest including the calculated cardiac arrest score

Factor	Derivation set (n = 127)	Validation set (n = 62)	p Value
Time to return of spontaneous circulation	37.7 ± 41.8	35.5 ± 35.7	0.71
CPR in progress (%)	23 (18.1)	16 (25.8)	0.22
Systolic blood pressure < 90 mmHg (%)	22 (17.3)	7 (11.3)	0.28
Systolic blood pressure ≥ 90 mmHg (%)	82 (64.6)	39 (62.9)	0.82
Intermittent perfusing rhythm (%)	16 (12.6)	18 (29.0)	0.005
Ventricular fibrillation (%)	112 (88.2)	57 (91.9)	0.43
Bradyarrhythmia or asystole (%)	15 (11.8)	5 (8.1)	0.43
Acute ST elevation on ECG (%)	32 (25.2)	22 (35.5)	0.14
Comatose (%)	90 (70.9)	40 (64.5)	0.38
Arousable (%)	19 (15.0)	7 (11.3)	0.49
Alert and oriented (%)	18 (14.2)	15 (24.2)	0.09
Cardiac arrest score			
0 (%)	35 (27.6)	19 (30.6)	0.66
1 (%)	35 (27.6)	17 (27.4)	0.98
2 (%)	31 (24.4)	10 (16.1)	0.20
3 (%)	26 (20.5)	16 (25.8)	0.41

Abbreviations: CPR = cardiopulmonary resuscitation, ECG = elctrocardiogram.

note, 41 (32.3%) and 20 (32.3%), p = 0.99, of the derivation and validation sets, respectively, had a history of heart disease prior to presentation.

Variables Known in the Emergency Department

Clinical factors including the calculated cardiac arrest scores available in the emergency department are given in Table III. Of note, fewer patients in the derivation set had an intermittent perfusing rhythm recorded by the paramedics prior to arrival. Of all cases coded as either asystole or bradyarrhythmia, 96% were indeed asystole. Otherwise the derivation and validation groups were similar with respect to clinical scenario and calculated cardiac arrest scores. The neurologic survival rate (discharge to home with little or no neurologic impairment, i.e., able to care for self) was 50 of 127 (39.3%) and 29 of 62 (46.8%) for the derivation and validation groups, respectively, p = 0.33. Likewise, the overall survival to discharge was 53 of 127 (41.7%) and 33 of 62 (53.2%), respectively, p = 0.14. Neurologic and vital outcomes for both patient groups, stratified by the cardiac arrest score ascertained in the emergency department, are displayed in Figures 1 and 2, respectively.

Validation of the Cardiac Arrest Score

The correlation between the derivation and validation sets at the four levels of the cardiac arrest score was 0.99 ($p < 0.0001$) for neurologic survival and $r = 0.98$ ($p < 0.0001$) for the overall survival probabilities. The coefficient of determination (R^2) was 0.98 and 0.96, respectively, for these relationships, indicating that virtually all of the variation observed in

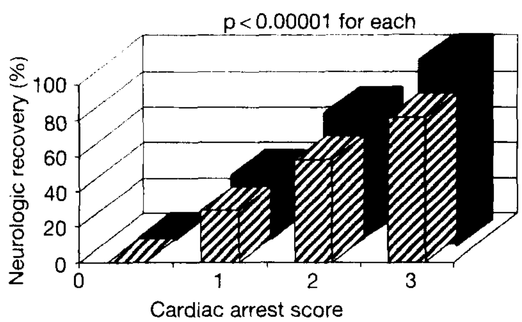

FIG. 1 Neurologic outcome stratified by initial cardiac arrest score. Neurologic recovery is defined as discharged to home and able to care for self. Derivation set, n = 127; validation set, n = 62. ▨ = derivation, ■ = validation.

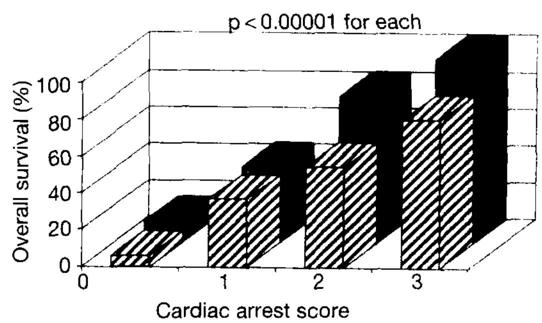

FIG. 2 Overall survival stratified by initial cardiac arrest score. Derivation set, n = 127; validation set, n = 62. ▨ = derivation, ■ = validation.

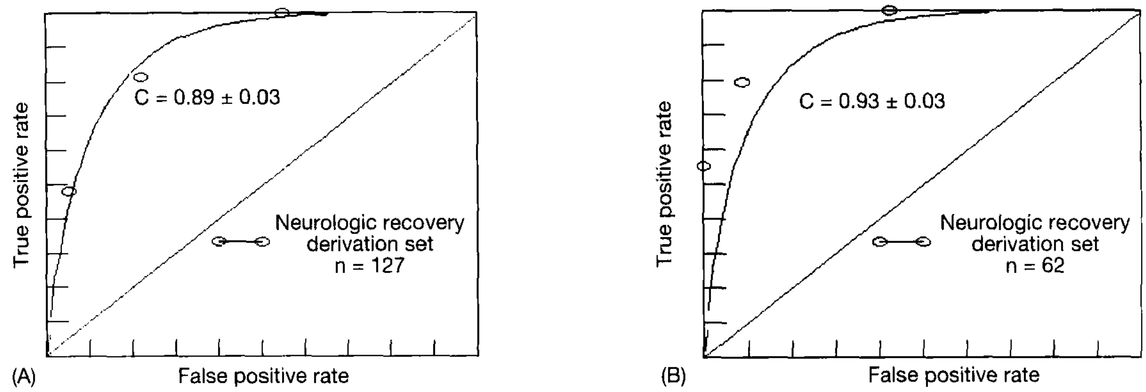

FIG. 3 Receiver operator characteristic curve for the cardiac arrest score applied to the derivation (A) and validation sets (B) of cardiac arrest victims for the outcomes of neurologic survival defined as discharged to home and able to care for self. The open ovals represent ascending levels of the score (0,1,2,3) from least to most favorable. The parameter "C" represents the calculated area under the curve and the relative value of the score as a diagnostic test. A null value for "C" is considered 0.50, representing the area beneath the straight line.

the validation set was predicted by the derivation set. To evaluate this relationship further, cumulative proportions of those neurologically surviving and those with overall survival to discharge were calculated for each level of the score. These were then treated as cumulative scales and tested using the alpha reliability statistic which was 0.99 and 0.98 for the two outcomes, respectively (both $p<0.0001$). This corroborated a high degree of predictive agreement between the probability of survival from the derivation set and the observed survival in the validation set by ascending cardiac arrest score achieved.

Utility of the Cardiac Arrest Score as a Diagnostic Test

The predicted and observed proportions of those surviving were evaluated using decision statistics and ROC curves displayed in Figures 3 and 4. There were no significant differences between the C values for the pairs of curves for neurologic and overall survival ($p<0.05$ for all pairwise comparisons). Similarly, the diagnostic accuracy of the cardiac arrest score was 75 and 79% in the derivation and validation sets, respectively, for a score of three in predicting neurologic recovery. Similarly, the diagnostic accuracy of the same score in predicting discharge to home alive was 71 and 73%, respectively, for the two groups. These pairs of proportions were not significantly different and indicate a high degree of diagnostic consistency in the most favorable cardiac arrest score. The overall likelihood ratios for the 42/189 scores of three were 13.23 [95% confidence interval (CI) 5.20–34.59] and 8.86 (95% CI 3.81–21.19) for neurologic recovery and overall survival, respectively.

Discussion

Coronary artery disease has a predominant role in sudden death.[9, 13–20] Only recently has primary angioplasty used in ST-segment elevation infarction been undertaken in cardiac arrest survivors.[10, 11] The impetus to identify and validate a

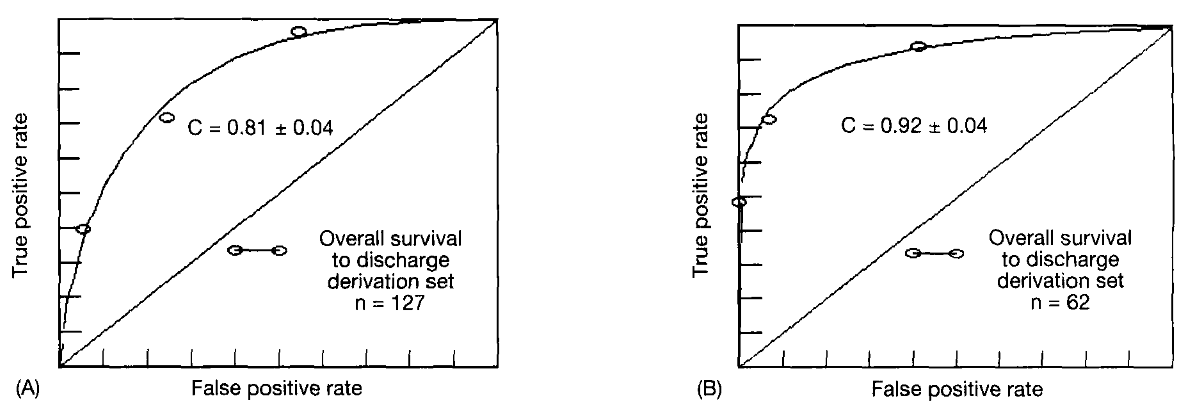

FIG. 4 Receiver operator characteristic curve for the cardiac arrest score applied to the derivation (A) and validation sets (B) of cardiac arrest victims for the outcome of survival to hospital discharge. The open ovals represent ascending levels of the score (0,1,2,3) from least to most favorable. See the legend for Figure 3A and B for an explanation of the value "C."

decision support tool to find those individuals who are likely to survive has become evident since a repeat cardiac arrest after admission may be fatal. In fact, in our derivation set study, we observed unstable arrhythmias after admission in nearly 50% of cases with repeat cardiac arrest being associated with a 93% mortality rate.[1,2]

Previous studies have been limited due to cumbersome evaluation methods involving laboratory measurements from serum and cerebrospinal fluid, electroencephalography, and neurology consultation. These techniques often involve a waiting period where the patient is supported and monitored, essentially closing the window of opportunity for reperfusion therapy. Furthermore, these methods have never been subjected to prospective validation with decision and agreement statistics.[8,9,21]

The cardiac arrest score that we have derived from a select group of patients in whom the details of the events were known utilizes a few relatively simple clinical data elements and an uncomplicated scoring scheme. This paper fully validates this scoring scheme as a useful and consistent decision support tool for the emergency physician and cardiologist for counseling patients and families. Furthermore, if the clinical scenario warrants immediate angiography, the decision to proceed with intervention is supported in those patients with a favorable cardiac arrest score (score = 3) based on revascularization outcomes reported in the literature.[11,22–26]

In terms of survival, the predictive accuracy of our model with respect to the area under the ROC curve (C = 0.81–0.92) is comparable with if not superior to general models developed to predict in-hospital mortality by Green and the Healthcare Financing Administration (C = 0.63–0.64) and the Severity of Illness Index developed by Horn and co-workers (C = 0.72–0.83).[27,28] Our model capitalizes on a specific event in which the details are known by the paramedics and emergency personnel very early in the clinical course with no need to rely on International Classification of Disease (ICD-9) codes assigned after hospitalization.

The limitations of this study include selection bias with respect to inclusion of cases where there was no ambiguity in terms of the duration of cardiopulmonary resuscitation, blood pressure measurement, or assessment of alertness. All patients had witnessed arrests. The scoring scheme cannot be applied in cases in which the time of the arrest is not known or when the etiology is not suspected to be cardiac in origin. Although we acknowledge that our study groups were highly selected, our observed survival rates of 41.7 and 53.2% are consistent with a 40% rate observed in one of the largest studies of cardiac arrest published.[29]

Conclusion

We have developed and now validated a useful and consistent decision support tool that can be employed by emergency department personnel and cardiologists in the early counseling of cardiac arrest victims and families with respect to prognosis. In addition, cases with favorable scores may be considered candidates for early angiography and revascularization if the clinical scenario suggests acute myocardial ischemia as the precipitant for the arrest.

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References

1. Thompson RJ, McCullough PA, Kahn JK, O'Neill WW: Early prediction of death and neurologic outcome in out-of-hospital sudden death survivors in the emergency department. *Circulation* 1996;94:I-356
2. Thompson RJ, McCullough PA, Kahn JK, O'Neill WW: Prediction of death and neurologic outcome in the emergency department in out-of-hospital cardiac arrest survivors. *Am J Cardiol* 1998;81: 17–21
3. Myerburg RJ, Castellanos A: Cardiac arrest and sudden cardiac death. In *Heart Disease* (Ed. Braunwald E), p. 756–789. Philadelphia: W.B. Saunders Company, 1992
4. Myerburg RJ, Kessler KM, Castellanos A: Sudden cardiac death: Epidemiology, transient risk, and interventional assessment. *Ann Intern Med* 1993;119:1187–1197
5. Hurwitz JL, Josephson ME: Sudden cardiac death in patients with chronic coronary heart disease. *Circulation* 1993;85(suppl I): I43–I49
6. Baum RS, Alvarez H, Cobb LA: Survival after resuscitation from out of hospital ventricular fibrillation. *Circulation* 1974;50:1231–1235
7. Gray WA, Capone RJ, Most AS: Unsuccessful emergency medical resuscitation—are continued efforts in the emergency room justified? *N Engl J Med* 1991;325:1393–1398
8. Longstreth WT, Diehr P, Inui TS: Prediction of awakening after out of hospital cardiac arrest. *N Engl J Med* 1983;308:1378–1382
9. Myerburg RJ, Conde CA, Sung RJ, Mauorga-Cortes A, Mallon SM, Sheps DS, Appel RA, Castellanos A: Clinical electrophysiologic and hemodynamic profile of patients resuscitated from prehospital cardiac arrest. *Am J Med* 1980;68:568–576
10. Kahn JK, Glazier S, Swor R, Savas V, O'Neill WW: Primary coronary angioplasty for acute myocardial infarction complicated by out-of-hospital cardiac arrest. *Am J Cardiol* 1995;75:1069–1070
11. Spaulding CM, Joly LM, Rosenberg A, Monchi M, Weber SN, Dhainaut JF, Carli PN: Immediate coronary angiography in survivors of out-of-hospital cardiac arrest. *N Engl J Med* 1997;336: 1629–1633
12. AHA Medical/Scientific Statement Writing Group: Utstein-style guidelines for uniform reporting of laboratory CPR research. *Circulation* 1996;94:2324–2336
13. Freidman M, Manwaring JH, Rosenman RH, Donlon G, Ortega P, Grube SM: Instantaneous and sudden deaths: Clinical and pathological differentiation in coronary artery disease. *J Am Med Assoc* 1973; 225:1319–1328
14. Liberthson RR, Nagel EL, Hirshman JC, Nussenfeld SR, Blackbourne BD, Davis JH: Pathophysiologic observations in post-hospital ventricular fibrillation and sudden cardiac death. *Circulation* 1974;49:790–798
15. Perper JA, Kuller LH, Cooper M: Arteriosclerosis of coronary arteries in sudden unexpected deaths. *Circulation* 1975;52(suppl III): III27–III33
16. Roberts WC, Buja LM: The frequency and significance of coronary arterial thrombi and other observations in fatal acute myocardial infarction. *Am J Med* 1972;52:425–443
17. Reichenbach DD, Moss NS, Meyer E: Pathology of the heart in sudden cardiac death. *Am J Cardiol* 1983;39:865–872

18. Goldstein S, Landis R, Leighton R, Ritter G, Vasu CM, Lantis A, Serokman R: Characteristics of the resuscitated out-of-hospital cardiac arrest victim with coronary heart disease. *Circulation* 1981;64:977–984
19. Davies MJ, Thomas AC, Knapman PA, Hangartner JR: Intramyocardial platelet aggregation in patients with unstable angina suffering sudden ischemic cardiac death. *Circulation* 1986;73:418–427
20. Kragel AH, Gertz SD, Roberts WC: Morphologic comparison of frequency and types of acute lesions in the major epicardial coronary arteries in unstable angina pectoris, sudden coronary death and acute myocardial infarction. *J Am Coll Cardiol* 1991; 18:801–808
21. Rabinowitz AJ, Maloney JD: Survivors of sudden cardiac death: A rational approach to evaluation and therapy of patients surviving ventricular fibrillation. *Clev Clin J Med* 1992;59:166–172
22. Manolis AS, Rastegar H, Estes NAM III: Effects of coronary artery bypass grafting on ventricular arrhythmias: Results with electrophysiological testing and long term follow up. *PACE* 1993;16: 984–991
23. O'Rourke RA: Role of myocardial revascularization in sudden cardiac death. *Circulation* 1992;85(suppl I):I112–117
24. Kelly P, Ruskin JN, Vlahakes GJ, Buckley MJ Jr, Freeman CS, Garan H: Surgical coronary revascularization in survivors of prehospital cardiac arrest: Its effects on ventricular arrhythmias and long term survival. *J Am Coll Cardiol* 1990;15:267–273
25. Every NR, Fahrenbruch CE, Hallstrom AP, Weaver WD, Cobb LA: Influence of coronary bypass surgery on subsequent outcome of patients resuscitated from out of hospital cardiac arrest. *J Am Coll Cardiol* 1992;19:1435–1439
26. Kron IL, Lerman BB, Haines DE, Flanagan TL, DiMarco JP: Coronary bypass grafting in patients with ventricular fibrillation. *Ann Thorac Surg* 1989;48:85–89
27. Green J, Wintfeld N, Sharkey P, Passman LJ: The importance of severity of illness in assessing hospital mortality. *J Am Med Assoc* 1990;263:241–246
28. Horn SD, Horn RA: Reliability and validity of the severity of illness index. *Med Care* 1986;24:159–178
29. Cobbe SM, Dalziel K, Ford I, Marsden AK: Survival of 1476 patients initially resuscitated from out of hospital cardiac arrest. *Br Med J* 1996;312:1633–1637