Effectiveness of Bystander Cardiopulmonary Resuscitation and Survival Following Out-of-Hospital Cardiac Arrest

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Objective.—To examine the independent relationship between effectiveness of bystander cardiopulmonary resuscitation (CPR) and survival following out-of-hospital cardiac arrest.

Design.—Prospective observational cohort.

Setting.—New York City.

Participants.—A total of 2071 consecutive out-of-hospital cardiac arrests meeting Utstein criteria.

Intervention.—Trained prehospital personnel assessed the quality of bystander CPR on arrival at the scene. Satisfactory execution of CPR required performance of both adequate compressions and ventilations in conformity with current American Heart Association guidelines.

Main Outcome Measure.—Adjusted association between CPR effectiveness and survival. Survival was defined as discharge from hospital to home.

Results.—Outcome was determined on all members of the inception cohort—none were lost to follow-up. When the association between bystander CPR and survival was adjusted for effectiveness of CPR in the parent data set (N=2071), only effective CPR was retained in the logistic model (adjusted odds ratio [OR]=5.7; 95% confidence interval [CI], 2.7 to 12.2; *P*<.001). Of the subset of 662 individuals (32%) who received bystander CPR, 305 (46%) had it performed effectively. Of these, 4.6% (14/305) survived vs 1.4% (5/357) of those with ineffective CPR (OR=3.4; 95% CI, 1.1 to 12.1; *P*<.02). After adjustment for witness status, initial rhythm, interval from collapse to CPR, and interval from collapse to advanced life support, effective CPR remained independently associated with improved survival (adjusted OR=3.9; 95% CI, 1.1 to 14.0; *P*<.04).

Conclusion.—The association between bystander CPR and survival in out-of-hospital cardiac arrest appears to be confounded by CPR quality. Effective CPR is independently associated with a quantitatively and statistically significant improvement in survival.

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PREVIOUS investigations of the relationship between effectiveness of bystander cardiopulmonary resuscitation (CPR) performed by lay persons and survival from out-of-hospital cardiac arrest have produced contradictory results.[1-3] The few studies that have demonstrated an association between CPR effectiveness and outcome had a minority of resuscitations initiated by lay persons, were vulnerable to both selection and detection bias, and were unadjusted for potentially confounding variables.[1,2] Researchers who have been unable to demonstrate a clear relationship between CPR effectiveness and outcome include, most notably, the Seattle, Wash, investigators.[3]

Despite this, CPR has received widespread promotion both in the United States and abroad.[4,5] If effectively performed CPR has an independent impact on outcome, this would provide some justification for the substantial resources invested in the training and recertification of lay persons in CPR.

The purpose of this analysis was to examine the nature and extent of the relationship between quality of bystander CPR and survival following out-of-hospital cardiac arrest.

METHODS

Case Identification

Victims of cardiac arrest were classified as receiving bystander CPR if persons at the scene were attempting either rescue breathing or sternal compressions. Effective bystander CPR was defined as performance of both adequate ventilations and compressions in conformity with current American Heart Association (AHA) guidelines.[5] Operationally, criteria for effective CPR were that mouth-to-mouth rescue breathing produce visible expansion of the chest wall and that a carotid or femoral pulse be palpable during compressions.[6] Assessment of CPR effectiveness was determined by the first prehospital personnel to arrive at the scene. All these individuals, at a minimum, were professional emergency medical technicians with an average of 4 years of experience and current AHA certification in basic life support.

Assessment of Validity of Methods

To validate the ability of prehospital personnel to distinguish effective from ineffective CPR, we constructed a 3×3 matrix to examine all nine possible combinations of ventilations and compressions, categorizing each of these two components of CPR independently as (1) effective, (2) ineffective because of inappropriate rate, or (3) ineffective because of inappropriate depth. A single-rescuer CPR scenario was developed for each of these nine combinations, rehearsed with experienced CPR instructors, and presented to two groups of prehospital professionals. Each individual was asked to score compressions and ventilations independently as adequate (meeting current AHA guidelines) or inadequate. For analysis, CPR was coded as effective only if both ventilations and compressions were rated as adequate. Otherwise, CPR was coded as ineffective. All CPR was performed on the Skillmeter Resusci-Annie (Laerdal Medical, Armonk, NY), using the analog readout as the criterion standard for rate and depth of ventilations and compressions. One of the authors (G.L.) ensured adherence to each of the test scenarios throughout the validation process.

Data Acquisition

Immediately following termination of the arrest in the field or transport of the patient to the emergency department, all relevant information was relayed to the New York City Cardiac Arrest Registry using a previously piloted and refined data collection instrument administered at all times by a cadre of six paramedics trained by the investigators. The particulars of the data collection process, including case identification and outcome tracking, have been described in detail previously.[7] Cases were all out-of-hospital cardiac arrests in which resuscitation was attempted in New York City during a period of 6 months.

All variables collected conformed to Utstein guidelines for core events and core time intervals.[8]

Data Analysis

The single target outcome variable was survival, defined as discharge from hospital to home. This end point was chosen because it is unambiguous and offers some measure of functional status. Individuals whose level of neurologic function required transfer to a chronic care facility were coded as nonsurvivors. Univariate associations between survival and categorical variables were examined with the χ^2 test or Fisher's exact test, as appropriate. Differences in elapsed time intervals between survivors and nonsurvivors were examined using the Wilcoxon-Mann-Whitney test.

We were interested in analysis of two different data sets: the parent data set of the 2071 qualifying cardiac arrests and the subset of the 662 patients who received CPR.

In the first instance, we constructed a logistic model with bystander CPR and CPR effectiveness as the independent variables and survival as the single dependent outcome variable. This model was constructed to examine the extent to which the univariate association between bystander CPR and survival might be confounded by CPR effectiveness.

In the second instance, because we were interested in the independent relationship between CPR effectiveness and survival, we constructed a series of stepwise logistic regression models to adjust for potentially confounding variables that were associated with survival in the univariate analyses. The single target dependent variable for all models was survival. Effectiveness of CPR was included as an independent variable in each model. The following independent variables were then added to the model one at a time: (1) witness status; (2) initial rhythm (coded as ventricular fibrillation/ventricular tachycardia [VF/VT] vs asystole/pulseless electrical activity); (3) estimated time interval from collapse to initiation of CPR (CPR interval); (4) estimated time interval from collapse to initiation of advanced life support (ALS interval) (ALS was defined as AHA standard, rhythm-appropriate intervention)[9]; and (5) an unweighted composite variable coded on a 0- to 4-point scale, assigning one point each for a witnessed event, initial rhythm VF/VT, CPR interval of 4 minutes or less, and ALS interval of 8 minutes or less. These demarcations of time intervals have been shown to be associated with survival.[10] Adjusted odds ratios (ORs) for CPR effectiveness derived from the logistic models are expressed with 95% confidence intervals (CIs) and accompanied by multivariate P values.

The number of independent variables was limited to two per model by design, so the ratio of outcome events (number of survivors) to the number of independent variables equaled approximately 10, thus avoiding "overfitting" of the models to this data set.[11]

All statistical analyses were performed using SAS software, version 6.04 (SAS Institute Inc, Cary, NC).

Human Subject Considerations

This investigation was approved by the Committee on Clinical Investigation of the Albert Einstein College of Medicine and the Institutional Review Board of the Health and Hospitals Corporation of New York City.

RESULTS

After exclusion of 914 arrests of noncardiac cause and 258 arrests occurring after ambulance arrival, there were 2071 arrests meeting Utstein criteria available for analysis.[7] In 99% of cases, information on CPR effectiveness was obtained through direct telephone contact with prehospital personnel on the shift during which the arrest occurred, thus minimizing recall bias. All patients transferred from hospital to chronic care facilities expired within 6 months and were coded as nonsurvivors. Final outcome was determined on all 2071 cases meeting entry criteria—none were lost to follow-up. Overall survival was 1.4% (30/2071) and has been reported previously.[12]

Those individuals who received bystander CPR had a survival of 2.9% (19/662) vs a survival of 0.8% (11/1405) for those who did not receive bystander CPR (OR=3.7; 95% CI, 1.7 to 8.8; $P<.001$) (four patients had missing data on CPR status). When this univariate association was adjusted for quality of CPR, only effective CPR was retained in the logistic model (adjusted OR=5.7; 95% CI, 2.7 to 12.2; $P<.001$).

Of the 32% of individuals (662/2067) on whom bystander CPR was attempted, 46% (305/662) had it performed effectively. Of these, 4.6% (14/305) survived. Among those 357 patients with ineffective CPR, 29% (102/357) received effective compressions and ineffective ventilations for a 2.0% survival. Seven percent (26/357) received ineffective compressions and effective ventilations for a 0.0% survival. In the remaining 64% of cases (229/357), neither compressions nor ventilations were effective for a survival of 0.6%. Of those with ineffective CPR, 1.4% (5/357) survived (95% CI for an absolute

Relationship of Effective Bystander Cardiopulmonary Resuscitation (CPR) to Survival, Adjusting for All Other Variables Associated with Outcome*

Independent Variables	Logistic Model Coefficient	Adjusted OR	95% CI for Adjusted OR
Effective CPR only	...	3.4†	1.1-12.1 ($P<.02$)
Effective CPR adjusted for collapse seen or heard by witness	1.5221	4.6	1.3-16.2 ($P<.02$)
Effective CPR adjusted for initial rhythm (VT/VF vs all other rhythms)	1.5771	4.8	1.4-17.3 ($P<.02$)
Effective CPR adjusted for interval from collapse to bystander CPR	1.3250	3.8	1.0-13.7 ($P<.05$)
Effective CPR adjusted for interval from collapse to advanced life support	1.2984	3.7	1.0-13.4 ($P<.05$)
Effective CPR simultaneously adjusted for all above variables‡	1.3453	3.9	1.1-14.0 ($P<.04$)

*OR indicates odds ratio; CI, confidence interval; ellipses, not applicable; VT/VF, ventricular tachycardia/ventricular fibrillation.

†Crude OR for effective CPR.

‡Unweighted composite variable coded on a scale of 0 to 4, assigning one point each for a witnessed event, initial rhythm VF/VT, interval from collapse to bystander CPR of 4 minutes or less, and interval from collapse to advanced life support of 8 minutes or less.

difference of 3.2% in survival between effective and ineffective CPR, 0.5% to 5.8%; $P<.02$). The crude OR of survival for effective vs ineffective CPR was 3.4 (95% CI, 1.1 to 12.1; $P<.02$).

There was no difference in survival when inadequate compressions (0.7%) were compared with absent compressions (0.0%). Similarly, survival among the inadequate ventilation group was 1.1%, and among those receiving no ventilation, survival was 1.2% ($P>.99$ for both comparisons by Fisher's exact test).

Among those who received bystander CPR, the following variables were associated with survival in the univariate analyses: witness status ($P<.02$), initial rhythm ($P<.001$), CPR interval ($P<.05$), ALS interval ($P<.01$), and CPR effectiveness ($P<.007$). The Table displays the ORs for the independent association between CPR effectiveness and survival following individual and aggregate adjustment for each of the variables in the logistic model.

To adjust for the possibility that short-term outcome may have biased observer assessment of CPR effectiveness, we constructed a logistic model in which long-term outcome, as measured by survival, and short-term outcome, as measured by return of spontaneous circulation, were the independent variables with effective CPR as the dependent variable. Only survival was retained in the model (adjusted OR=4.5; 95% CI, 3.5 to 5.8; $P<.02$), suggesting that the independent association between survival and CPR effectiveness was not confounded by short-term outcome.

Results of Validation of Methods

An independent validation set of 69 prehospital personnel, composed of 37 emergency medical technicians and 29 paramedics, assessed effectiveness of CPR as performed on a mannequin by experienced CPR instructors. These individuals had not been certified in CPR for an average of 2 years. As noted previously, we developed scenarios for each of the nine possible pairwise combinations of ventilations and compressions. A recording device attached in series to a mannequin and observation by one of the authors (G.L.) verified adherence to each scenario. In 594 instances (66 individuals × nine scenarios), prehospital personnel demonstrated a 96% sensitivity (95% CI, 87% to 99%) and a 96% specificity (95% CI, 95% to 98%) for an overall correct classification of CPR as effective or ineffective in 96% of all standardized CPR scenarios (95% CI, 95% to 98%).

COMMENT

Cardiopulmonary resuscitation is considered a critical link in the "chain of survival" leading from the initial moments of cardiac arrest to successful resuscitation.[13] Because most cardiac arrests occur out-of-hospital, those called on to perform CPR are likely to be lay persons. This circumstance has led to a proliferation of public programs designed to train large numbers of persons in the community. Although Cummins and Eisenberg have shown most persuasively that bystander CPR contributes to survival independently of witness status,[14] not all investigations have reached this conclusion,[15] and others have continued to question it.[16] We reasoned that if CPR truly saves lives, then effectively performed CPR would save more lives than ineffectively performed CPR. However, we could find only two investigations that demonstrated a univariate association between effectiveness of CPR and survival from out-of-hospital cardiac arrest. Neither of these studies adjusted for potentially confounding variables.[1,2]

Of particular note, in Seattle, where survival rates are high, investigators have been unable to detect an improvement in survival associated with effective performance of CPR. These authors suggest that this finding may be attributed to the rapid response of prehospital personnel.[3] Our findings support this speculation. In New York City, where the interval from collapse to arrival of prehospital personnel is substantially longer than in Seattle,[12] we found that after adjustment for witness status, initial rhythm, interval from collapse to CPR, and interval from collapse to ALS, effective bystander CPR was independently associated with a roughly threefold to fourfold proportionate increase in survival when compared with ineffective CPR (Table).

We also found that the univariate association between bystander CPR and outcome in the entire cohort (N=2071) was confounded by whether the CPR was effective. This further suggests that the way in which CPR is performed has an impact on survival.

Inferences that can be drawn from these data are limited by at least two features: internal validity may be compromised by reliance on prehospital personnel to distinguish effective from ineffective CPR accurately, and external validity may be impaired by our low survival. With regard to the first limitation, independent validation of our methods, using nine different CPR scenarios as the criterion standard, suggests that prehospital personnel are able to make this distinction with about 96% sensitivity, specificity, and accuracy.

With regard to the second limitation, although our survival rate is similar to that reported from other densely populated urban areas,[17] it is far less than that of midsized urban, suburban, and rural emergency medical service systems.[18-22] In a system with a high mortality rate following out-of-hospital cardiac arrest, absolute differences in survival associated with any intervention, although statistically significant, are likely to be quantitatively small. However, a small number of survivors also makes it less likely that an association between any intervention and survival would be detected because of low statistical power. Thus, demonstration of a relationship between effective CPR and outcome, particularly in the setting of low survival, is compatible with the hypothesis that a larger effect of properly performed CPR would be evident in a system with higher survival. We conclude that the association between bystander CPR and survival is confounded by CPR quality and that effective bystander CPR, when compared with ineffective CPR, is independently associated with a quantitatively and statistically significant improvement in outcome following out-of-hospital cardiac arrest. This increment in survival, which was apparent despite infrequent and often poorly performed CPR, may be most evident in prehospital care systems in which elapsed time intervals between collapse and arrival of prehospital personnel are lengthy, thus requiring bystanders to perform CPR for relatively prolonged periods.

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