ORIGINAL ARTICLE

Early Cardiopulmonary Resuscitation in Out-of-Hospital Cardiac Arrest

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ABSTRACT

BACKGROUND

Three million people in Sweden are trained in cardiopulmonary resuscitation (CPR). Whether this training increases the frequency of bystander CPR or the survival rate among persons who have out-of-hospital cardiac arrests has been questioned.

METHODS

We analyzed a total of 30,381 out-of-hospital cardiac arrests witnessed in Sweden from January 1, 1990, through December 31, 2011, to determine whether CPR was performed before the arrival of emergency medical services (EMS) and whether early CPR was correlated with survival.

RESULTS

CPR was performed before the arrival of EMS in 15,512 cases (51.1%) and was not performed before the arrival of EMS in 14,869 cases (48.9%). The 30-day survival rate was 10.5% when CPR was performed before EMS arrival versus 4.0% when CPR was not performed before EMS arrival (P<0.001). When adjustment was made for a propensity score (which included the variables of age, sex, location of cardiac arrest, cause of cardiac arrest, initial cardiac rhythm, EMS response time, time from collapse to call for EMS, and year of event), CPR before the arrival of EMS was associated with an increased 30-day survival rate (odds ratio, 2.15; 95% confidence interval, 1.88 to 2.45). When the time to defibrillation in patients who were found to be in ventricular fibrillation was included in the propensity score, the results were similar. The positive correlation between early CPR and survival rate remained stable over the course of the study period. An association was also observed between the time from collapse to the start of CPR and the 30-day survival rate.

CONCLUSIONS

CPR performed before EMS arrival was associated with a 30-day survival rate after an out-of-hospital cardiac arrest that was more than twice as high as that associated with no CPR before EMS arrival. (Funded by the Laerdal Foundation for Acute Medicine and others.)

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Out-of-hospital cardiac arrest is a major public health concern, given that there are approximately 420,000 cases in the United States and 275,000 cases in Europe annually.[1-3] Decreasing the time to treatment is crucial for improving outcomes in cases of cardiac arrest.[4,5] As stated in American and European guidelines, the most important response measures that currently can be taken outside a hospital setting are recognizing early that a cardiac arrest is occurring, placing an alarm call, performing cardiopulmonary resuscitation (CPR), and performing defibrillation.[6,7] Globally, CPR is taught to millions of people each year. In Sweden, more than 3 million people (of a population of 9.7 million)[8] have undergone CPR training during the past three decades (Claesson A, Swedish Resuscitation Council: personal communication). However, in recent years, the value of bystander CPR has been debated in the medical community.[9,10] A major source of concern is the lack of a randomized clinical trial to show that bystander CPR is life-saving. Scientific documentation of the value of bystander CPR with regard to survival after an out-of-hospital cardiac arrest has been based on studies in animals and studies involving registry data, in which the preponderance of evidence has shown an association between CPR and survival.[11,12] The main effect of CPR is probably indirect, in that it may prolong the time window for defibrillation.[13,14] The sooner defibrillation can be performed, the better the chance of survival.[15,16]

In the current study, our primary aim was to assess whether CPR initiated before the arrival of emergency medical services (EMS) was associated with an increase in the 30-day survival rate among persons who collapsed due to an out-of-hospital cardiac arrest, with adjustment for several confounders, including the age and sex of the patient, the place and cause of the cardiac arrest, the initial cardiac rhythm, the EMS response time, the time from collapse to the call for EMS, and the time from collapse to defibrillation. A secondary aim was to assess the association between the estimated time from collapse to the start of CPR and the 30-day survival rate.

METHODS

POPULATION

We included all cases of EMS-treated and bystander-witnessed out-of-hospital cardiac arrests recorded in the Swedish Cardiac Arrest Registry from January 1, 1990, through December 31, 2011. Nonwitnessed cases and cases witnessed only by the EMS crew were excluded.

SWEDISH CARDIAC ARREST REGISTRY

The Swedish Cardiac Arrest Registry now includes more than 90% of all persons who had an out-of-hospital cardiac arrest in Sweden and in whom CPR was attempted. It is a national quality registry funded by the Swedish Association of Local Authorities and Regions. All EMS centers in Sweden report data to the registry in accordance with the Utstein style[17]; the reporting includes completion of a standard form with detailed descriptions of the circumstances, time delays, and forms of intervention in cases of out-of-hospital cardiac arrest in which CPR was attempted. The form is reviewed and completed by the head physician of the ambulance organization in each county. This registry has been thoroughly described elsewhere.[18]

Cases are included in the registry only if there was no breathing and no sign of circulation in the patient and if CPR, defibrillation, or both were started. In recent years, there has been a progressive increase in retrospective monitoring, including cross-checking between the registry and the local EMS registry.

Ethics approval for the use of data from the Swedish Cardiac Arrest Registry was obtained from the Regional Ethics Board, Gothenburg, Sweden. The protocol for this registry study is available with the full text of this article at NEJM.org.

DISPATCH AND AMBULANCE ORGANIZATION

In Sweden, there are approximately 850 ambulances serving 9.7 million citizens.[19] There is a two-tiered EMS system in Sweden for responses to all medical emergencies: the first tier consists of EMS units that can respond to an out-of-hospital cardiac arrest with a basic level of life support, and units in the second tier are able to provide an advanced level of life support. Data on EMS units in both tiers are included in the Swedish Cardiac Arrest Registry and in this analysis. Sweden has 15 dispatch centers, all of which are similar in their organization and emergency-call processing. The dispatcher uses a standard protocol with a specific questionnaire for the identified emergency. In cases of suspected cardiac arrest, an ambulance is dispatched, and dispatchers are instructed to offer the caller a chance to perform telephone-assisted CPR (i.e., if the caller is not trained in CPR, instructions on how to perform CPR are provided). This system was introduced in 1998.[20] The guidelines for CPR changed during the study period; major alterations occurred in 2000, 2005, and 2010 in response to changes in international guidelines.[7,21,22] These changes included the elimination of the pulse check and more focus on chest compressions, with more and deeper compressions used.

In 2006, a dual-dispatch system was implemented in Stockholm that engages firefighters and police in addition to EMS. However, in most parts of Sweden, this dual-dispatch system was not implemented until 2011; we estimate that approximately 5% of the cases that were included in this study occurred after that system was implemented.

INITIATION OF CPR

Data on the start of CPR included whether CPR was started before the arrival of EMS (yes or no) and the estimated time between the patient's collapse and the initiation of CPR. In addition, patients who underwent CPR during the latter part of the study (January 1, 2009, through December 31, 2011) were categorized in one of two groups — patients who did and those who did not undergo telephone-assisted CPR.

TIMES OF EVENTS AND PROCEDURES

The times of events and procedures (day, hour, and minute) were reported for the patient's collapse, the call to the dispatch center, the dispatch of EMS, the arrival of EMS at the scene, the start of CPR (either before or after the arrival of EMS), and defibrillation (if the patient had ventricular fibrillation or pulseless ventricular tachycardia as the first recorded arrhythmia). The time of the emergency call, the time of dispatch, and the time of the arrival of EMS were recorded digitally and collected from the dispatch center, whereas the times of collapse, the start of CPR, and defibrillation were based on statements from witnesses, first responders, and EMS clinicians.

CEREBRAL FUNCTION AT DISCHARGE

Since November 2008, the Swedish Cardiac Arrest Registry has collected information on cerebral function at hospital discharge in a subgroup of 30-day survivors. Cerebral function is described with the use of the cerebral performance categories score, in which category 1 or 2 indicates favorable cerebral function, category 3 or 4 indicates poor cerebral function, and category 5 indicates brain death (Table S1 in the Supplementary Appendix, available at NEJM.org).

STATISTICAL ANALYSIS

Univariate analyses were performed with the use of Fisher's exact test for dichotomous variables and the Mann–Whitney U test for continuous variables. Logistic regression was used for the calculation of odds ratios with corresponding confidence intervals and for analyses of interaction. A propensity analysis was performed to adjust for potential confounders. First, a propensity score for receipt of CPR before EMS arrival was calculated by means of multiple logistic regression. The variables included in the score were age, sex, cause of cardiac arrest, place of cardiac arrest, initial cardiac rhythm, year of cardiac arrest, time from collapse to the call for EMS, time from the call for those services to the arrival of EMS, and among patients with an initial rhythm of ventricular tachycardia or ventricular fibrillation, time from collapse to defibrillation. Using forward stepwise selection, we tested for interactions between the variables and included them in the score if the P value was less than 0.20. The score was then used as an adjustment factor in a logistic-regression models.

All tests were two-sided, and a P value of less than 0.05 for the primary objective and of less than 0.01 for all other analyses was considered to indicate statistical significance. SAS software, version 9.3 (SAS Institute), was used for all statistical analyses.

RESULTS

CARDIAC ARREST AND CPR

Data on 61,781 patients who had an out-of-hospital cardiac arrest and underwent CPR were reported to the registry during the period from 1990 through 2011. Among these incidents of cardiac arrest and CPR, 7898 were witnessed by EMS responders (12.8%), and 17,935 (29.0%) were not witnessed. Information on whether the incident was witnessed was missing in 4585 cases (7.4%); these cases were excluded from the analysis.

Among the patients who had a bystander-

Table 1. Baseline Characteristics of the Patients.*

Variable	CPR Started after Arrival of EMS (N=14,869)	CPR Started before Arrival of EMS (N=15,512)	P Value
Median age (10th to 90th percentile) — yr	74 (54–86)	69 (46–84)	<0.001
Female sex — %	30.2	26.8	<0.001
Cardiac cause of cardiac arrest — %	73.4	72.4	0.04
Collapse at home — %	73.2	55.5	<0.001
VF or VT as initial ECG rhythm — %	30.7	41.3	<0.001
Median intervals (10th to 90th percentile) — min			
Collapse to call for EMS	4 (0–11)	3 (0–10)	<0.001
Call for EMS to arrival of EMS	6 (3–15)	8 (3–20)	<0.001
Collapse to start of CPR	11 (5–23)	4 (0–17)	<0.001
Patients in VF or VT — no.	4194	5900	
Median time from collapse to defibrillation (10th to 90th percentile) — min	11 (6–21)	13 (7–24)	<0.001

* The percentages of patients with missing data for each variable were as follows: age, 3.3%; sex, 3.2%; cause of cardiac arrest, 6.7%; place of collapse, 0.8%; initial electrocardiographic (ECG) rhythm, 7.9%; delay from collapse to call for emergency medical services (EMS), 20.0%; delay from call for EMS to arrival of EMS, 6.4%; delay from collapse to start of CPR, 21.2%; and delay from collapse to defibrillation, 5.3%. The proportions of missing data were similar between the two groups. P value calculations included data only from those patients who did not have missing data. CPR denotes cardiopulmonary resuscitation, VF ventricular fibrillation, and VT ventricular tachycardia.

witnessed out-of-hospital cardiac arrest, 682 (2.2%) were not included because of a lack of information on whether CPR had been given before the arrival of EMS. Of the remaining 30,681 patients, 300 (1.0%) were not included because information on 30-day survival was missing. Among the 30,381 patients who had a bystander-witnessed out-of-hospital cardiac arrest and recorded data on both the start of CPR and survival, 15,512 (51.1%) received CPR before the arrival of EMS, and 14,869 (48.9%) did not (Fig. S1 in the Supplementary Appendix).

CHARACTERISTICS OF THE PATIENTS

As compared with patients who did not undergo CPR before EMS arrival, patients who underwent CPR before EMS arrival were younger, and their collapse was less likely to have occurred at home; this group also included fewer women (Table 1). Patients in the group that underwent CPR before EMS arrival were more often found to be in ventricular fibrillation, despite no greater frequency in that group of cardiac causes as the assumed underlying cause of cardiac arrest (the higher frequency of ventricular fibrillation was also found when adjustment was made for confounders [Table S2 in the Supplementary Appendix]). The times from collapse to the call to EMS and from collapse to the start of CPR were shorter in the group that underwent CPR before the arrival of EMS. However, the time from the call for EMS until the arrival of EMS and the time from collapse to defibrillation if the patient had been found to be in ventricular fibrillation were longer in this group. The prolonged EMS response time in the group that received CPR before EMS arrival was found regardless of whether the patient had initial arrhythmia and regardless of the place in which the out-of-hospital cardiac arrest occurred (Table S3 in the Supplementary Appendix). Changes over time in the number of persons trained in CPR, the performance of early CPR, and survival are shown in Figure 1.

SURVIVAL

The 30-day survival rate was 10.5% among patients who underwent CPR before EMS arrival, as compared with 4.0% among those who did not (P<0.001). There was a significantly higher survival rate among patients who received CPR before EMS arrival in all the subgroups analyzed (Fig. 2). A significant interaction was found between receipt of CPR before EMS arrival and both the sex of the patient and the place in which the cardiac arrest occurred (P=0.002 and P=0.001, respectively, for the interaction). The increase in the survival rate among patients who underwent CPR before EMS arrival was more marked among men than among women and more marked when the out-of-hospital cardiac arrest occurred outside the patient's home (e.g., in a public location) than when it occurred inside the patient's home.

Table 2 shows the 30-day survival rate in relation to the time between the patient's collapse and the start of CPR. Overall, there was a significant association between the time to the start of CPR and the survival rate: the survival rate decreased with an increase in the time to the start of CPR. The association was found in all the subgroups analyzed.

TELEPHONE-ASSISTED CPR AND SURVIVAL

In a subgroup analysis (with data collected from January 1, 2009, through December 31, 2011), a total of 35% of patients who underwent CPR before EMS arrival had CPR performed by a person who received telephone-assisted CPR instructions (Table S4 in the Supplementary Appendix). These patients had a 30-day survival rate of 10.9%, as compared with a rate of 15.4% among those who received early CPR performed by a person who did not receive telephone-assisted instructions (P<0.001).

POST HOC PROPENSITY ANALYSIS

A post hoc propensity score was calculated that took into account the year of the out-of-hospital cardiac arrest and all the variables listed in Table 1 (except the time from collapse to defibrillation) and relevant interactions among them. After adjustment for the propensity score, the difference in the 30-day survival rate between the two groups (CPR before vs. after EMS arrival) remained highly significant (odds ratio, 2.15; 95% confidence interval [CI], 1.88 to 2.45; P<0.001) (Table 3). Because data were missing for several variables, we also performed multiple imputation by means of the Markov chain Monte Carlo method, which resulted in a corresponding odds ratio of 2.05 (95% CI, 1.84 to 2.28). In an analysis of the subgroup of patients who were found to be in ventricular fibrillation in which the time between collapse and defibrillation was included in the propensity score, there was also a significant difference between the groups (odds ratio, 2.27; 99% CI, 1.84 to 2.81; P<0.001).

CEREBRAL FUNCTION AMONG SURVIVORS

In total, there were 474 patients who survived for 30 days after collapse and for whom information on the cerebral performance categories score, for which higher scores indicate greater disability, was available. At the time of discharge from the hospital, 81% of these patients had a score of category 1, 14% a score of category 2, 5% a score of category 3, less than 1% a score of category 4, and less than 1% a score of category 5.

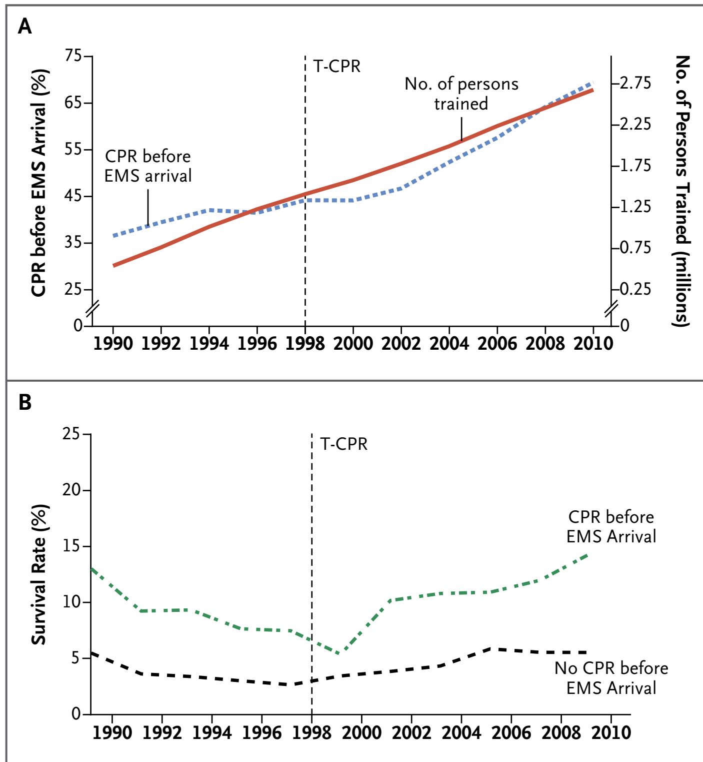

Figure 1. Changes over Time in CPR Training, the Performance of Early CPR, and Survival Rates.

Panel A shows the number of persons in Sweden who were trained in cardiopulmonary resuscitation (CPR) and the proportion of patients in whom CPR was started before the arrival of emergency medical services (EMS). Panel B shows the survival rate when CPR was given and when CPR was not given before EMS arrival. In both panels, the vertical line (T-CPR) indicates the year in which telephone-assisted CPR was introduced in Sweden.

Subgroup	Survival Rate — No CPR before EMS Arrival	Survival Rate — CPR before EMS Arrival	Patients with No CPR before EMS Arrival	Patients with CPR before EMS Arrival	Odds Ratio (95% CI)
	%		no.		
All patients	4.0	10.5	14,869	15,512	2.80 (2.47–3.18)
Age					
≤72 yr	5.6	12.7	6,405	9,043	2.44 (2.07–2.87)
>72 yr	2.9	7.9	8,011	5,929	2.84 (2.30–3.50)
Sex					
Female	4.1	8.3	4,343	4,053	2.14 (1.67–2.73)
Male	4.1	11.5	10,036	11,085	3.02 (2.60–3.51)
Cause of cardiac arrest					
Cardiac	4.2	11.5	10,205	10,452	2.94 (2.53–3.41)
Noncardiac	3.4	8.5	3,694	3,993	2.62 (1.99–3.45)
Location of cardiac arrest					
At home	3.1	5.9	10,783	8,544	1.97 (1.64–2.37)
Other location	6.7	16.3	3,949	6,855	2.72 (2.26–3.27)
Initial ECG rhythm					
VF or VT	9.4	20.1	4,194	5,900	2.43 (2.07–2.85)
Asystole or PEA	1.5	3.2	9,487	8,394	2.12 (1.62–2.78)
Year of cardiac arrest					
1990–1995	3.8	9.7	3,892	2,629	2.75 (2.09–3.62)
1996–2001	3.0	6.9	4,697	3,563	2.38 (1.80–3.14)
2002–2007	4.6	10.7	3,562	3,923	2.46 (1.93–3.14)
2008–2011	5.5	13.4	2,562	5,278	2.64 (2.07–3.88)

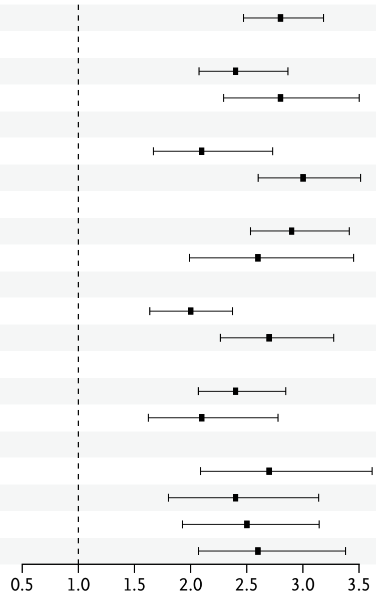

Figure 2. Subgroup Analysis of Survival Rates.
ECG denotes electrocardiographic, PEA pulseless electrical activity, VF ventricular fibrillation, and VT ventricular tachycardia.

DISCUSSION

In the current study, we found increased survival rates among patients who had an out-of-hospital cardiac arrest and underwent CPR before the arrival of EMS. This finding is consistent with those of other studies.[23-25] We also found that if bystander CPR was started before the arrival of EMS, the emergency call was initiated more rapidly, which suggests that bystanders with CPR training are better than bystanders without such training at recognizing that a cardiac arrest is occurring and taking action. Despite these findings, the time from collapse to the arrival of EMS, as well as the time from collapse to first defibrillation, was longer in cases in which CPR was given before EMS arrived. Thus, the survival rate among patients who received CPR before EMS arrived was increased despite the fact that the time to defibrillation was prolonged.

There are several possible explanations for the observation that the survival rate was increased even when the time to defibrillation was prolonged; one explanation is that CPR maintains a certain degree of circulation, which may prevent ventricular fibrillation from deteriorating to asystole before EMS arrives. A possible explanation for the longer EMS response times in the group that received early CPR is that having a longer period between the call to EMS and EMS arrival may increase the likelihood that CPR is started before EMS arrival (e.g., if neighbors call in, someone able to perform CPR passes by, or telephone-assisted CPR is provided). Finally, some EMS systems in Sweden dispatch the fire department when there is no ambulance available, which results in a longer time between the call to EMS and EMS arrival.

Patients who underwent CPR before the arrival of EMS were less likely to have collapsed at home; this finding is consistent with previous findings that are best explained by the observation that a preponderance of in-home, out-of-hospital cardiac arrests are witnessed by elderly persons in the home. Such persons are most often not educated in CPR or are not capable of performing it.[26,27]

The increase in the survival rate if CPR was given before the arrival of EMS was greater when

Table 2. The Rate of 30-Day Survival in Relation to the Time from Collapse to the Start of CPR.

Subgroup	No. of Patients with Data	Survival Rate According to Time from Collapse to Start of CPR*			
		0–3 min	4–8 min	9–14 min	>14 min
		percent			
All patients	23,931	15.6	8.7	4.0	0.9
Age					
≤72 yr	12,169	19.2	11.0	5.6	1.5
>72 yr	10,968	10.8	6.7	2.6	0.4
Sex					
Female	6,424	12.2	7.5	4.5	1.0
Male	16,842	16.9	9.4	3.8	0.9
Cardiac cause					
Yes	16,534	16.6	9.5	4.0	0.9
No	5,979	12.9	6.5	3.8	1.0
Location of cardiac arrest					
At home	15,179	9.2	6.0	3.3	0.7
Other location	8,579	21.6	12.9	5.7	1.7
VF or VT as initial ECG rhythm					
Yes	8,213	26.4	15.6	7.9	2.7
No	13,941	4.6	3.1	1.6	0.4
Year of cardiac arrest					
1990–1995	5,068	16.3	9.6	3.5	0.7
1996–2001	6,397	11.9	6.7	3.1	0.5
2002–2007	5,605	15.2	9.9	4.8	0.8
2008–2011	6,666	17.0	8.9	4.9	2.0

* P<0.001 in all subgroups for the association between the time from collapse to the start of CPR and 30-day survival.

the out-of-hospital cardiac arrest took place outside the patient's home, possibly because in that setting, bystanders are often younger and may be more likely to be trained in CPR. Our finding that CPR before the arrival of EMS was more likely to increase the survival rate among men than among women could be explained by findings in one study that more women who have an out-of-hospital cardiac arrest have them at home.[28]

The importance of early CPR was further supported by the strong association we observed between the time from collapse to the start of CPR and the 30-day survival rate. This association was found among all patients and among all subgroups that we evaluated.

There was an increase over time in the proportion of persons who received CPR before the arrival of EMS when they had an out-of-hospital cardiac arrest. We speculate that widespread teaching of CPR to laypeople, the implementation of telephone-assisted CPR, and more frequent dispatch of firefighters and the police may have contributed to the increase. Other strategies in addition to population-based CPR training are also important. In this issue of the *Journal*, Ringh et al.[29] report increases in the rates of bystander-initiated CPR associated with the use of a mobile-phone positioning system for dispatching CPR-trained lay volunteers to respond to nearby out-of-hospital cardiac arrests.

Our study has some limitations. First, all time data were obtained from the Swedish Cardiac Arrest Registry, and in this registry, the time of collapse is estimated, as is the time of the start of CPR, although other time data — for exam-

Table 3. Odds of 30-Day Survival among Patients Who Underwent CPR before EMS Arrival.*

Group and Propensity Score Adjustment	No. of Patients with Data	Odds Ratio for 30-Day Survival†	95% Confidence Interval	99% Confidence Interval
All patients	30,381	2.80	2.55–3.09	2.47–3.18
Propensity score	19,153			
Unadjusted		2.95	2.60–3.34	2.50–3.47
Adjusted		2.15	1.88–2.45	1.80–2.56
Propensity score excluding time from collapse to call	22,928			
Unadjusted		2.74	2.45–3.06	2.37–3.18
Adjusted		1.92	1.70–2.16	1.64–2.24
Propensity score for patients with missing data for time from collapse to call	3,775			
Unadjusted		1.92	1.48–2.50	1.36–2.71
Adjusted		1.26	0.95–1.68	0.87–1.84
Patients with VF or VT as initial ECG rhythm‡	10,094	2.76	2.50–3.06	2.42–3.16
Propensity score	7,025			
Unadjusted		2.63	2.27–3.04	2.16–3.19
Adjusted		2.27	1.94–2.67	1.84–2.81

* Adjusted results were adjusted for a propensity score that included the following variables, except where indicated: age, sex, cause of cardiac arrest, place of cardiac arrest, initial cardiac rhythm, year of cardiac arrest, time from collapse to the call for EMS, and time from the call for EMS to the arrival of EMS. Unadjusted results were not adjusted for the propensity score but are from an analysis that involves the same group of patients as the adjusted results (i.e., the analysis included patients for whom the data used to calculate the propensity score were not missing).

† Odds ratios for 30-day survival are for the comparison of patients who underwent CPR before EMS arrival with those who did not.

‡ The propensity score includes the variables included in the main propensity score plus the time from collapse to defibrillation.

ple, the timing of the call to EMS, the dispatch of EMS, and the arrival of EMS — are digitally registered at the dispatch center and appear to be accurate in most cases. Second, approximately 25% of all persons with an out-of-hospital cardiac arrest in whom CPR is started are not prospectively reported to the registry, although data on these patients have been reported retrospectively since 2011. Thus, reporting has become more complete over time. Third, the protocols for EMS providers have changed over time as a result of changes in guidelines every 5 years. The EMS response time has concomitantly increased. As time passes, the initial rhythm of ventricular fibrillation deteriorates into asystole, and therefore the proportion of patients found to be in ventricular fibrillation decreases.[13] However, the number of Swedes educated in CPR has increased, and the proportion of cases in which CPR is started before EMS arrival has increased — changes that are associated with increased survival rates in this study. Finally, the use of therapeutic hypothermia, coronary revascularization, and implantable cardioverter–defibrillators has been implemented in recent years, which may confound our results. These limitations, however, are tempered by the strengths of our study, including our large sample, the use of bystander-witnessed cases to better characterize delays, and our robust statistical analysis.

In conclusion, among patients who had an out-of-hospital cardiac arrest, CPR performed before the arrival of EMS was associated with a rate of 30-day survival that was more than twice as high as that associated with no CPR before EMS arrival. The association with a good outcome was greater when the time to the initiation of CPR was short.

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No potential conflict of interest relevant to this article was reported.

Disclosure forms provided by the authors are available with the full text of this article at NEJM.org.

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