Cardiac arrest survival after implementation of automated external defibrillator technology in the in-hospital setting

Matthew S. Forcina, MD; Ali Y. Farhat, MD; William W. O'Neill, MD; David E. Haines, MD

Background: **Survival from ventricular tachycardia (VT) or ventricular fibrillation (VF) arrest is inversely related to delay to defibrillation. The automated external defibrillator (AED) has improved survival after out-of-hospital VT/VF arrest by decreasing time to defibrillation. The purpose of this study was to determine whether survival to discharge after in-hospital cardiac arrest caused by VT/VF could be improved via an institution-wide change from a standard monophasic defibrillator to a biphasic defibrillator with AED capability.**

Methods and Results: **After extensive staff education, all standard defibrillators were replaced by AEDs at a single institution. Outcomes were analyzed for 1 year before the change and 1 year after the change using a prospective database. In patients whose initial rhythm was VT/VF, AEDs were not associated with improvement in time to first shock (median 1 minute for both cohorts, $p = 0.79$) or survival to discharge (31% vs. 29%, $p = 0.8$) compared with standard defibrillators. In patients whose initial rhythm was asystole or pulseless electrical activity, AEDs were associated with a significant decrease in survival (15%) compared with standard defibrillators (23%, $p = 0.04$). The overall AED cohort showed no difference in survival to discharge compared with the standard cohort (18% vs. 23%, $p = 0.09$).**

Conclusions: **Replacement of standard monophasic defibrillators with biphasic AEDs was associated with unchanged survival after in-hospital VT/VF arrest and decreased survival after in-hospital asystole or pulseless electrical activity arrest. (Crit Care Med 2009; 37:000–000)**

KEY WORDS: heart arrest; tachyarrhythmia; defibrillation; cardiopulmonary resuscitation; survival

Cardiac arrest causes 250,000 out-of-hospital deaths in the United States every year (1). In arrests caused by ventricular tachycardia (VT) or ventricular fibrillation (VF), survival decreases rapidly as time to defibrillation increases (2, 3). Automated external defibrillators (AEDs) have been shown to reduce time to first shock (4, 5) and improve survival in out-of-hospital VF arrest (6, 7), leading to an American Heart Association class I recommendation for their use in this setting (8). The importance of early defibrillation is paramount; AED use conferred no survival advantage in studies failing to demonstrate an improvement in time to defibrillation (9, 13).

In contrast to out-of-hospital cardiac arrest, outcomes after in-hospital cardiac arrest have been relatively unchanged for the past 40 years (14). In a recent multicenter registry, survival to discharge was only 18% (11% for asystole [AS] or pulseless electrical activity [PEA], 36% for VT/VF) (15). Data on in-hospital VT/VF arrest suggest an inverse relationship between time to defibrillation and survival (16, 18). Use of AEDs has been proposed as a strategy to improve in-hospital cardiac arrest survival via prompt defibrillation by floor personnel who witness a VT/VF arrest. Observational studies of in-hospital VT/VF arrest resuscitated with an AED have reported survival to discharge of 33% to 56% (19–21). To date, only one study has compared outcomes of in-hospital cardiac arrest resuscitated with AEDs to standard defibrillators (22). Despite limited evidence, American Heart Association guidelines recommend consideration of AED use in the in-hospital setting as a means to shorten time to first shock to within 3 minutes of collapse (8).

Based on favorable AED outcomes for out-of-hospital arrest, all standard defibrillators were converted to AEDs at William Beaumont Hospital. First responders would have the capability to defibrillate before the arrival of the cardiopulmonary resuscitation (CPR) team. The purpose of this study was to determine whether outcomes were improved, worsened, or unchanged in patients with in-hospital cardiac arrest by use of AEDs vs. standard defibrillators. It was hypothesized that compared with standard defibrillators, AEDs would reduce time to first shock and improve survival after in-hospital cardiac arrest caused by VT/VF, but have no effect on survival after in-hospital cardiac arrest caused by AS/PEA.

METHODS

Study Setting. The study was conducted at William Beaumont Hospital, a 1066-bed tertiary care teaching hospital in Royal Oak, MI with 58,000 inpatient admissions per year and 115,500 emergency room visits per year. Monitoring facilities included 102 critical care beds, 144 stepdown beds, and 128 additional beds. Average daily occupancy of these beds was 91% from January 1, 2004 to December 31, 2006. Cardiopulmonary arrests on stepdown units or general wards elicited a response from a CPR team comprising a pharmacist, a respiratory technician, two critical care nurses, and a physician (internal medicine resident, internal medicine subspecialty fellow, or internal medicine attending) capable of performing advanced cardiac life support (ACLS). In other settings, a cardiopulmonary arrest elicited an ACLS response by

From the Departments of Cardiovascular Medicine (MSF, DEH) and Medicine (AYF), Royal Oak, Michigan; and Miller School of Medicine at the University of Miami (WWO), Miami, Florida.

Supported, in part, by the generous funding of Dominic S. and Francis Moceri.

Dr. O'Neill is a consultant to Medtronic, Inc. (modest compensation); Dr. Haines has received honorarium from Medtronic, Inc. (modest compensation); Drs. Forcina and Farhat have no potential conflicts.

For information regarding this article, E-mail: dhaines@beaumont.edu

DOI: 10.1097/CCM.0b013e3181960ff3

personnel already present in that particular nursing unit.

Defibrillation Protocol. Before September 11, 2004, the hospital was equipped exclusively with standard monophasic defibrillators (Zoll, Chelmsford, MA; Hewlett Packard, Palo Alto, CA; Physio-control, Redmond, WA; n = 229). Cardiac arrests elicited a basic life support (BLS) response from floor personnel, and ACLS and defibrillation were performed only after CPR team arrival. From September 11, 2004 to March 8, 2005, standard monophasic defibrillators were completely replaced by AED-capable biphasic defibrillators (Medtronic Lifepak 20, Minneapolis, MN; n = 240) at a total cost to the institution of >1,976,000$. After March 8, 2005, a cardiac arrest on the stepdown unit or general ward elicited AED application by floor personnel (with shock delivery if appropriate) in addition to BLS. First shock energies were 200 J in both the standard defibrillator group (recommended) and the AED group (automatic). Shock energies were escalated to a maximum of 360 J. Once the CPR team arrived, the AED mode was discontinued and the device was then used as a manual biphasic defibrillator. A cardiac arrest in the intensive care unit (ICU), emergency department, operating room, recovery room, or cardiac catheterization/electrophysiology laboratory elicited a response from the ACLS-trained personnel already present without a separate CPR team response, and the AED was used exclusively as a manual biphasic defibrillator. Thus, AED devices were not uniformly used in the AED mode.

AED Training. Training of 1791 nurses, nurse anesthetists, and medical/surgical residents consisted of a mandatory computer tutorial (30–60 minutes) and either 30 minutes of hands-on classroom instruction for BLS providers or 60 minutes of hands-on classroom instruction for ACLS providers. Training was timed to take place 1 to 2 weeks before the device was deployed on a particular nursing unit. After deployment of AEDs, approximately 500 nurses underwent optional repeat training, and all new hires were also required to complete the training.

Study Population. The study population consisted of 561 inpatients, emergency department patients, and outpatients undergoing diagnostic or therapeutic procedures who suffered a cardiac arrest with a CPR attempt. Two time periods were examined: 1 year immediately preceding introduction of AEDs (standard cohort: September 11, 2003 to September 10, 2004) and 1 year immediately after complete deployment of AEDs and staff training (AED cohort: March 9, 2005 to March 8, 2006). CPR data were prospectively recorded on a standardized form during the resuscitation attempt by a dedicated scribe and timekeeper, and retrospectively examined for this study. Demographic and outcome data were obtained from the electronic medical record and patient chart in compliance with the policies of the institutional Human Investigation Committee after committee approval of the protocol. All variables and outcomes were described according to the Utstein style (23, 24) and operational definitions provided by the National Registry for Cardiopulmonary Resuscitation.

Inclusion/Exclusion Criteria. All adult inpatients, emergency department patients, and outpatient procedure patients suffering from cardiac arrest requiring chest compressions, defibrillation, or both were screened for inclusion. If a patient had multiple cardiac arrests during a single hospitalization, only the first event was included. CPR attempts were excluded for return of perfusing rhythm before chest compressions or defibrillation, modified Do Not Resuscitate status that disallowed chest compressions or defibrillation, internal defibrillation, events beginning outside of the hospital, or an incomplete CPR record.

Definitions. Patients with cardiac arrest were grouped as shown in Figure 1. Initial rhythm during cardiac arrest was described as either "initial VT/VF" or "initial AS/PEA." This latter group was divided into patients who developed VT/VF at any point during resuscitation ("late VT/VF") and patients who remained in AS/PEA for the entire resuscitation effort ("AS/PEA only"). CPR delay was defined as the time from first notification of the cardiac arrest (earliest time of arrest noted during review of standardized cardiac arrest form, nursing notes, progress notes, and telemetry strips) until the first clinical charting of shock or chest compressions.

Data Analysis. The primary outcomes were survival to discharge after initial VT/VF arrest and survival to discharge after initial AS/PEA arrest. Secondary outcomes included time to first shock (onset of VT/VF to first attempted defibrillation), shock effectiveness (immediate conversion to any rhythm other than VT/VF), return of spontaneous circulation (ROSC), CPR survival (ROSC $\geq$ 20 minutes), 24-hour survival, and survival to discharge. Time of arrest, onset of VT/VF, and time of first attempted defibrillation were abstracted from the standardized cardiac arrest form and telemetry printouts. Defibrillator clocks were not synchronized. Whether an arrest was monitored or witnessed was determined by telemetry records and examination of nursing and progress notes. Statistical analyses were completed on the categorical variables using a chi-square test when appropriate (expected frequency >5); otherwise, a Fisher's exact test was used. The continuous variables were analyzed using a Wilcoxon's rank sum test, a nonparametric approximation of the Student's t test based on the ranks of the values.

RESULTS

Baseline Characteristics. Patient classification by CPR rhythm is shown in Figure 1. Six hundred and forty-one initial cardiac arrests occurred during the study period. Eighty events met exclusion criteria. The standard cohort comprised 49.4% (277 patients) and the AED cohort comprised 50.6% (284 patients) of the final 561 patients reported.

Demographic and clinical characteristics of the patients included in the study analysis are listed in Table 1. There were no differences between the standard and AED cohorts with regard to age, sex, race, body mass index, illness category, or preexisting conditions. Prearrest medications were similar except for lower likelihood of angiotensin-converting enzyme inhibitor/angiotensin receptor blocker use in the AED cohort (20% vs. 29%, p = 0.02) compared with the standard cohort. When the initial VT/VF group was analyzed separately, there was similarly a lower likelihood of angiotensin-converting enzyme inhibitor/angiotensin receptor blocker use in the AED cohort (18 of 42 patients, 43%) compared with the standard cohort (10 of 45 patients, 22%; p = 0.04). There were no differences between cohorts in the initial AS/PEA group.

Cardiac Arrest Event Characteristics. There were no differences between cohorts with regard to the predominant rhythm observed during the arrest, the proportion of eligible patients who appropriately received a shock, whether the arrest was monitored/witnessed, the work shift during which the arrest occurred, CPR delay (the interval from recognition of cardiac arrest until initiation of resuscitative efforts), the interval from recognition of cardiac arrest to first administration of epinephrine, or length of resuscitation. Location of arrest was similar between study cohorts except for lower probability of arrest in the operating room/recovery room in the AED cohort (0.7%) compared with the standard cohort (3.3%; p = 0.03). When the initial VT/VF and initial AS/PEA groups were analyzed separately, there were no differences between cohorts in cardiac arrest event characteristics (Table 2).

Time to First Shock. In the initial VT/VF group, there was no difference in time to first shock in the AED cohort (median 1.0 minute) compared with the standard cohort (median 1.0 minute; p = 0.79). In the late VT/VF group, there was no difference in time to first shock in the AED cohort (median 0 minute) compared with the standard cohort (median 0 minute; p = 0.51). Time to first shock was stratified by location for both initial VT/VF (Table 3) and late VT/VF (data not

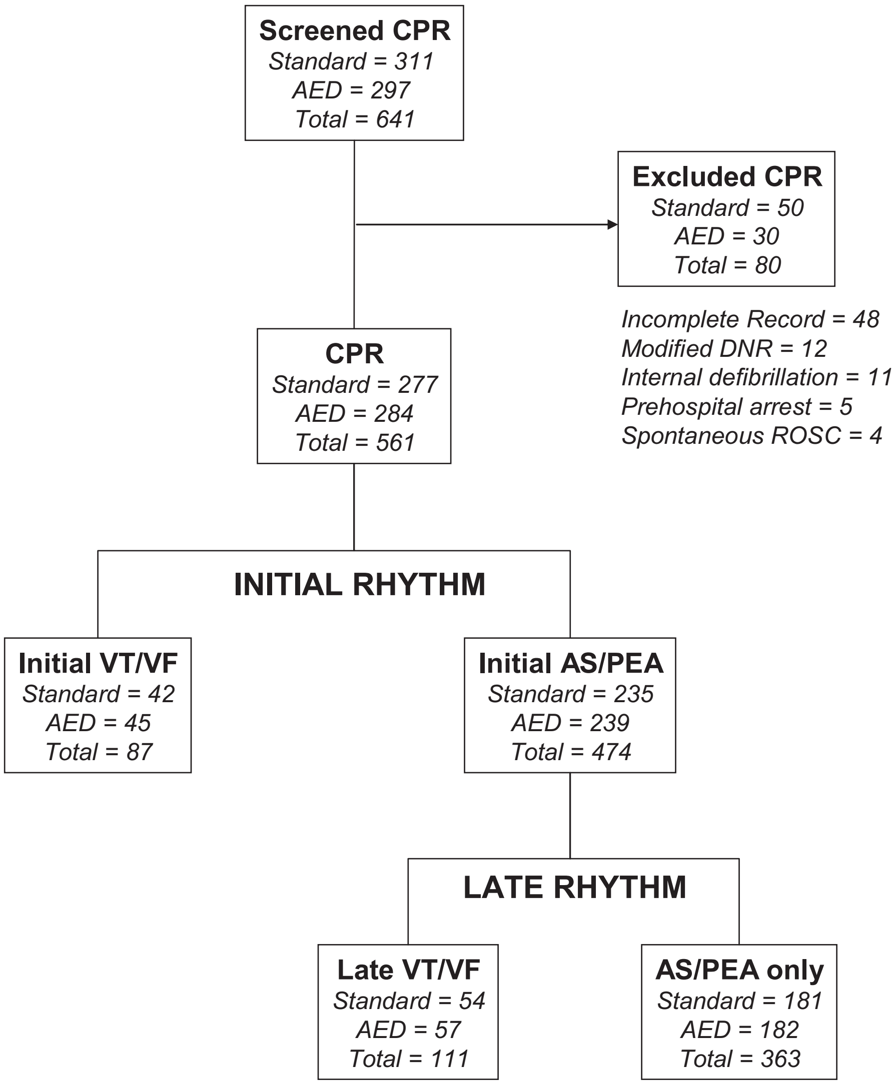

Figure 1. Patient groups. After exclusion, patients were first divided by initial rhythm into initial VT/VF and initial asystole or pulseless electrical activity (*AS/PEA*) groups. Initial AS/PEA patients were further divided into subgroups based on whether VT/VF subsequently developed during resuscitation (late VT/VF or AS/PEA only). *CPR*, cardiopulmonary resuscitation; *DNR*, Do Not Resuscitate; *ROSC*, return of spontaneous circulation; *VT*, ventricular tachycardia; *VF*, ventricular fibrillation; *AS*, asystole; *PEA*, pulseless electrical activity.

shown); no location showed a significant difference between cohorts.

First Responder Shocks. Because the stepdown units and the general wards were the locations in which the new defibrillators were used in the AED mode, outcomes in patients who received a shock by first responders were compared with those who were shocked after the CPR team arrived in these locations. Of the 20 patients in the AED cohort with VT/VF arrest in the stepdown/general ward, six (30%) were shocked before CPR team arrival (median time to first shock 1.5 minutes, range 0–3 minutes) and 13 (70%) were shocked coincident with or after CPR team arrival time (median time to first shock 2.0 minutes, range 0–16 minutes). CPR team arrival time was unavailable in one patient. In this small subset of patients, survival to hospital discharge was 17% for the patients shocked before CPR team arrival vs. 31% for those shocked by the CPR team (p = not significant).

Stratification of CPR Delay. CPR delay was stratified by the recorded rhythm and by the nursing unit location to assess whether confounding factors affected the outcome of resuscitative efforts. There was a trend toward longer CPR delay in the AED cohort compared with the standard cohort for all rhythm subgroups, but this achieved significance only in the late VT/VF subgroup. The longest CPR delays in the AED cohort occurred outside of the ICUs, particularly in general hospital wards. However, delays in CPR initiation in particular nursing units did not directly correlate with differences in survival (Table 4).

Clinical Outcomes. No difference in any primary or secondary outcome was seen in the initial VT/VF group, late VT/VF group, or in all patients. In patients with an initial rhythm of AS/PEA, survival to discharge was worse in the AED cohort compared with the standard cohort (15% vs. 23%, $p = 0.04$). In the AS/PEA-only group, patients in the AED cohort had decreased survival at 24 hours (36% vs. 46%, $p = 0.05$) and survival to hospital discharge (17% vs. 26%, $p = 0.04$) compared with patients in the standard cohort. Survival to discharge for initial VT/VF, late VT/VF, initial AS/PEA, and all patients did not differ between cohorts at any nursing unit location. The AS/PEA-only patients showed decreased survival in the ICU (Tables 5 and 6).

DISCUSSION

The aim of the current study was to determine the effect of AEDs on in-hospital resuscitation outcomes compared with standard defibrillators. Among patients with initial VT/VF during in-hospital resuscitation, AEDs failed to improve time to first shock or survival to discharge. Defibrillation by first responders before CPR team arrival occurred in only 30% of eligible patients, and survival in this small subset of patients was unimproved. Among patients with AS/PEA as the initial rhythm, AEDs were associated with decreased survival to discharge, primarily among patients who never had VT/VF during CPR (AS/PEA only). Survival in the overall group of 561 patients was unaffected by the availability of AED functionality. Use of the AED mode was associated with a trend toward increased CPR delay, but a direct causal link between CPR delay and survival was not identified.

Outcomes in Patients With VT/VF. Compared with standard defibrillators, AEDs conferred no advantage for any outcome in the initial VT/VF group. Although time to first shock was not reduced after the change to an AED, it is interesting to note that both cohorts received an initial shock within 3 minutes of loss of pulse (median 1 minute for both). The American Heart Association

Table 1. Demographic and clinical characteristics

	Standard (N = 277)	Automated External Defibrillator (N = 284)	p
Age	72 ± 14 (75)	71 ± 15 (75)	0.87
Sex (male)	153 (55%)	151 (53%)	0.62
Race			
White	203 (73.3%)	204 (71.8%)	0.70
Black	41 (14.8%)	57 (20.1%)	0.10
Hispanic	0 (0%)	2 (0.7%)	
Other	18 (6.5%)	13 (4.6%)	0.32
Unknown	15 (5.4%)	8 (2.8%)	0.12
Body mass index	27.3 ± 8.1 (26)	27.6 ± 8.5 (26)	0.96
Illness category			
Medical, cardiac	75 (27.1%)	74 (26.1%)	0.78
Medical, noncardiac	128 (46.2%)	144 (50.7%)	0.29
Surgical, cardiac	30 (10.8%)	33 (11.6%)	0.77
Surgical, noncardiac	39 (14.1%)	30 (10.6%)	0.20
Trauma	5 (1.8%)	3 (1.1%)	0.50
Preexisting conditions			
Myocardial infarction	117 (42%)	118 (42%)	0.87
Congestive heart failure	153 (55%)	150 (53%)	0.57
Coronary artery bypass graft	70 (25%)	60 (21%)	0.24
Diabetes mellitus	121 (44%)	108 (38%)	0.17
Renal insufficiency	112 (40%)	111 (39%)	0.74
Hypertension	212 (77%)	212 (75%)	0.60
Arrhythmia	128 (46%)	117 (41%)	0.23
Medications within 24 hrs of cardiac arrest			
Beta blocker	125 (45%)	122 (43%)	0.60
Angiotensin-converting enzyme inhibitor/ angiotensin receptor blocker	80 (29%)	58 (20%)	0.02
Amiodarone	51 (18%)	40 (14%)	0.16
Aspirin	108 (39%)	118 (42%)	0.54
Clopidogrel	41 (15%)	48 (17%)	0.50
Digoxin	36 (13%)	29 (10%)	0.30
Calcium channel blocker	49 (18%)	37 (13%)	0.13
Other cardiac	18 (6.5%)	20 (7.0%)	0.80

goal for time to first shock of <3 minutes (8) was met even before AEDs were introduced, and the addition of AEDs in this setting did not provide further benefit. These findings are similar to an out-of-hospital, controlled crossover AED study of 879 patients (25) that reported adding AEDs to BLS performed by first responders was not associated with improvement in survival compared with BLS alone because of the rapid response time of the paramedics. The authors concluded that AEDs are unlikely to provide additional benefit in the setting of a fast ACLS response time. Recent multicenter data (15) show that median delay to first in-hospital shock is only 1 minute. Thus, the current study indicates that survival benefit might not be expected by introducing AEDs to the in-hospital setting, particularly in nursing units where first responders are ACLS trained.

A recent multivariate regression analysis (18) identified clinical factors associated with delayed defibrillation (>2 minutes) in the setting of in-hospital VT/VF arrest, including black race, noncardiac admission diagnosis, arrest occurring in a hospital with fewer than 250 beds, unmonitored arrest, and arrest during the evening shift. Whether AEDs can improve in-hospital survival in these subgroups is a question worthy of future prospective study.

Only 30% of eligible initial VT/VF patients (those whose VT/VF arrests occurred on stepdown and general ward units) were shocked before CPR team arrival. Median time to first shock was 2 minutes among the 70% of eligible initial VT/VF patients shocked by the CPR team, again suggesting that a relatively quick CPR team response may have prevented the opportunity for defibrillation by first responders in AED mode in most cases. Alternatively, inability on the part of first responders to use the AED quickly or effectively (despite an educational program that accompanied AED deployment) may have contributed to the inability to demonstrate improved survival. The potential for worse outcomes using a device with AED capability was highlighted by a sentinel event in which both first responders and the CPR team failed to use the new defibrillator correctly, resulting in delayed shock administration (>10 minutes) while staff awaited automatic shock delivery.

Even if a small decrease in time to first shock can be realized with an AED, any consequent benefit may be negated by delayed initiation of resuscitation. Stratification of CPR delay by location revealed that nursing units using AED mode (stepdown and general ward) showed an increase in CPR delay; this delay was likely due to time spent locating and applying the AED pads and waiting for rhythm analysis. Furthermore, verbal prompts during resuscitation in AED mode may have encouraged prolonged "hands-off" periods during the resuscitation attempt. Minimization of interruption of chest compressions has been shown to improve witnessed VF survival in the out-of-hospital setting (26); it seems likely that AED-mediated pauses in chest compressions would be detrimental in the in-hospital setting as well. A prospective head-to-head comparison of AEDs programmed with standard CPR instructions to AEDs programmed with verbal instructions designed to maximize chest compressions could answer this important clinical question.

Termination of VT/VF was equally likely with a biphasic compared with a monophasic waveform for the initial VT/VF and late VT/VF groups. This is consistent with a recent blinded trial (27) of 168 patients with out-of-hospital VF arrest randomized to monophasic or biphasic shocks; despite favorable trends, no differences in shock effectiveness, ROSC, or survival to hospital admission were seen. Other studies have demonstrated improved shock effectiveness with a biphasic waveform (28–31). Neither waveform has been consistently associated with improved ROSC or survival to discharge (1). Shock energies were not available in the current study, so assessment of the effectiveness of lower energy biphasic shocks compared with higher energy monophasic shocks cannot be made.

Outcomes in Patients With AS/PEA. Because defibrillation plays no role in the management of AS/PEA, the investigators hypothesized that a changeover from standard defibrillators to AEDs would not affect outcomes in this group. AS/PEA

Table 2. Cardiac arrest event characteristics

	Standard (N = 277)	Automated External Defibrillator (N = 284)	p
Rhythm			
Initial AS/PEA	235 (85%)	239 (84%)	0.82
Initial VT/VF	42 (15%)	45 (16%)	0.82
Late VT/VF (VT/VF after initial AS/PEA)	54 (19%)	57 (20%)	0.86
AS/PEA only (AS/PEA for duration of CPR)	181 (65%)	182 (64%)	0.76
VT/VF receiving shock	39/42 (93%)	41/45 (91%)	1.00
Late VT/VF receiving shock	48/54 (89%)	55/57 (96%)	0.15
AS/PEA only receiving shock	4/181 (2.2%)	3/182 (1.6%)	0.72
Location			
Intensive care unit	102 (36.8%)	111 (39.1%)	0.58
Stepdown	54 (19.5%)	49 (17.3%)	0.49
General ward	76 (27.4%)	87 (30.6%)	0.40
Emergency room	18 (6.5%)	11 (3.9%)	0.16
Operating room/recovery room	9 (3.3%)	2 (0.7%)	0.03
Cardiac catheterization/electrophysiology lab	10 (3.6%)	19 (6.7%)	0.10
Other	8 (2.9%)	5 (1.8%)	0.37
Monitored/witnessed	246 (89%)	242 (85%)	0.21
Shift			0.30
Day	148 (53%)	164 (58%)	
Evening	129 (47%)	120 (42%)	
CPR delay (interval to initiation of CPR, min)			
Median (25th, 75th percentile)	0 (0, 1)	0 (0, 2)	0.08
Time to first epinephrine, initial AS/PEA (min)			
Median (25th, 75th percentile)	3.0 (1, 5)	2.0 (0, 5)	0.25
Time to first epinephrine, AS/PEA only (min)			
Median (25th, 75th percentile)	3.0 (1, 5)	2.0 (0, 5)	0.22
First shock effectiveness, initial VT/VF (%)	85	73	0.21
First shock effectiveness, late VT/VF (%)	71	78	0.39
CPR duration (min) (mean ± SD)	17.2 ± 14	16.5 ± 14	0.32

Table 3. Time to first shock, patients with VT/VF as initial rhythm by location

	Standard	Automated External Defibrillator	p
All locations	(n = 39)	(n = 41)	
	1.0 (0, 4)	1.0 (0, 2)	0.79
Intensive care unit	n = 15	n = 13	
	0 (0, 1)	1.0 (0, 2)	0.42
Stepdown	n = 7	n = 11	
	2.0 (0, 6)	1.0 (0, 5)	0.75
General ward	n = 8	n = 9	
	4.5 (2.5, 5.5)	2.0 (1, 5)	0.35
Emergency room	n = 3	n = 3	
	0 (0, 1)	0 (0, 2)	1.00
Operating room/recovery room	n = 1	n = 0	
	3.0		
Cardiac catheterization/electrophysiology lab	n = 4	n = 5	
	0 (0, 0.5)	0 (0, 0)	0.4
Other	n = 1	n = 0	
	13		
Location other than intensive care unit	n = 24	n = 28	
	2.0 (0, 5)	1.0 (0, 3)	0.32
Stepdown + general ward	n = 15	n = 20	
	4.0 (1, 6)	2.0 (0.5, 5)	0.32

Data are expressed as medians (25th, 75th percentile).

arrest outcomes (for both initial AS/PEA and AS/PEA-only groups) were unexpectedly worse after AEDs were introduced. Because the AS/PEA-only patients never received a shock from either an AED or a standard defibrillator, an unknown difference associated with the introduction of the AED must be implicated. In both the initial AS/PEA group and the AS/PEA-only subgroup, the AED cohort showed no differences in CPR delay, interval to first epinephrine, ROSC, or CPR survival compared with the standard patients. Increased CPR delay seen on nursing units using AED mode (stepdown and general ward) and the probable decreased proportion of resuscitation time spent performing chest compressions due to AED verbal instructions likely contributed to the overall decrease in survival in this group. Interestingly, these delays did not directly correlate with decreased survival in stepdown and general ward locations, specifically.

AS/PEA survival was worse in the ICU, where ACLS is immediately available. This finding suggests that unknown differences in CPR protocol between the cohorts may also have undermined the effectiveness of CPR. Differences in unavailable demographic or clinical factors or differences in postresuscitation care might also account for the survival decrease in the AED cohort.

Prior Studies. The observed lack of benefit associated with the introduction of AEDs stands in stark contrast to the findings of Zafari et al (22) who demonstrated an increase in cardiac arrest survival to discharge from 4.9% to 12.8% in all patients after switching from a monophasic defibrillator to biphasic AED in a single-center study at a Veterans Administration hospital from 1995 to 2002. The improvement in overall mortality was attributed solely to improved survival (37.5%) in patients whose initial rhythm was VT/VF. Rhythms other than VT/VF showed no difference in survival after AEDs were deployed.

This result is difficult to reconcile with the outcome of our study; however, it is likely that the extremely low survival before AED implementation, differences in comorbidities and acuity in a VA compared with a community hospital population, an almost exclusively male patient cohort, evolution of CPR guidelines, and changes in the Veterans Administration hospital system over the 7-year study period limit the generalizability of this result. The VA study did not capture time to first shock or effectiveness of first shock, so whether these factors contributed to the improvement in survival cannot be determined. It is possible that the observed survival benefit may have been due to improved CPR team response time, the intensive educational program that preceded AED introduction, or to the use of a biphasic waveform.

Limitations. In the current study, three separate interventions were introduced at one time: biphasic waveform devices replaced monophasic devices, AED mode replaced manual mode in cer-

Table 4. Cardiopulmonary resuscitation delay by rhythm and location

	Standard (N = 277)	Automated External Defibrillator (N = 284)	*p*
Initial VT/VF	0 (0, 1)	0 (0, 1)	0.55
Initial AS/PEA	0 (0, 1)	0 (0, 2)	0.10
AS/PEA only	0 (0, 1)	0 (0, 2)	0.53
Late VT/VF	0 (0, 0)	0 (0, 3)	0.02
Intensive care unit	0 (0, 0)	0 (0, 0)	0.70
Stepdown	0 (0, 2)	0 (0, 2)	0.69
General ward	0 (0, 3)	2.0 (0, 5)	0.004
Emergency room	0 (0, 1)	0 (0, 0)	0.05
Operating room/recovery room	0 (0, 0)	0 (0, 0)	1.00
Cardiac catheterization/electrophysiology lab	0 (0, 0)	0 (0, 0)	0.22
Other	0 (0, 3)	4.0 (0, 9)	0.26
Location other than intensive care unit	0 (0, 2)	0 (0, 4)	0.01
Stepdown + general ward	0 (0, 2)	1.0 (0, 5)	0.007

VT, ventricular tachycardia; VF, ventricular fibrillation; AS, asystole; PEA, pulseless electrical activity.

Data are expressed as medians (25th, 75th percentile).

Table 5. Clinical outcomes

	Standard	Automated External Defibrillator	*p*
Initial VT/VF			
ROSC	27/42 (64%)	30/45 (67%)	0.82
CPR survival	27/42 (64%)	28/45 (62%)	0.84
24-hr survival	18/42 (43%)	22/45 (49%)	0.57
Survival to discharge	12/42 (29%)	14/45 (31%)	0.80
Initial AS/PEA			
ROSC	166/235 (71%)	161/239 (67%)	0.44
CPR survival	142/235 (60%)	142/239 (59%)	0.82
24-hr survival	98/235 (42%)	81/239 (34%)	0.08
Survival to discharge	53/235 (23%)	36/239 (15%)	0.04
AS/PEA only			
ROSC	128/181 (71%)	128/182 (70%)	0.94
CPR survival	116/181 (65%)	114/182 (63%)	0.77
24-hr survival	84/181 (46%)	66/182 (36%)	0.05
Survival to discharge	47/181 (26%)	31/182 (17%)	0.04
Late VT/VF			
ROSC	38/54 (70%)	33/57 (58%)	0.17
CPR survival	26/54 (48%)	28/57 (49%)	0.92
24-hr survival	14/54 (26%)	15/57 (26%)	0.96
Survival to discharge	6/54 (11%)	5/57 (9%)	0.68
All patients			
ROSC	193/277 (70%)	191/284 (67%)	0.54
CPR survival	169/277 (61%)	170/284 (60%)	0.78
24-hr survival	116/277 (42%)	103/284 (36%)	0.17
Survival to discharge	65/277 (23%)	50/284 (18%)	0.09

VT, ventricular tachycardia; VF, ventricular fibrillation; ROSC, return of spontaneous circulation; CPR, cardiopulmonary resuscitation; AS, asystole; PEA, pulseless electrical activity.

tain nursing units, and an extensive educational campaign was conducted to encourage AED use. Because of the retrospective design of this study, it is difficult to ascribe any treatment effect to a single intervention. It is possible that the enhanced education that preceded AED deployment should have improved outcomes via the Hawthorne effect; however, the decreased survival in initial AS/PEA patients provides strong evidence that training was not a confounder. The two cohorts were sequential comparison groups, so a concurrent control group was not available. Evolution of ACLS protocols throughout the study may have introduced unavoidable differences in the conduct of resuscitations between the cohorts; however, new guidelines reemphasizing the paramount importance of chest compressions (32) should have actually improved outcomes in the later AED cohort. Outcomes arising from the introduction of AED-capable defibrillators might differ from one hospital to another, depending on differences in CPR training and skills, specialty of the hospital, or other factors.

The lack of survival improvement in VT/VF arrests may also be due to insufficient power to detect differences in outcomes. Although VF is present at first analysis of rhythm in about 40% of out-of-hospital cardiac arrests (32), VT/VF accounts for only 23% of all in-hospital cardiac arrests (15), and just 16% of the patients in this study. Only 45 VT/VF arrests occurred in the year after AED deployment, and only 20 were resuscitated in AED mode, with six of these patients receiving a shock before the arrival of ACLS providers. A longer period of observation would have allowed for increased numbers of VT/VF arrests and better assessment of AED effectiveness. The real time of arrest onset was unknown in unmonitored, unwitnessed events. In those cases, the onset of the arrest was timed from discovery of the patient and initiation of the resuscitation effort, and therefore underestimated this value in those cases. However, the percentage of unwitnessed arrests was similar among the two cohorts (Table 2).

CONCLUSIONS

AED-capable biphasic defibrillators failed to improve survival to discharge for in-hospital VT/VF arrest compared with standard monophasic defibrillators. It seems likely that failure to improve an already fast CPR team response time (and consequent failure to reduce time to first shock) may be responsible. These findings suggest that if AEDs are to be used in hospital, they should be deployed in facilities with only BLS capability or in areas where CPR team response and defibrillation may be delayed. An unexpected decrease in survival was associated with changeover to an AED among patients with in-hospital AS/PEA arrest, particularly among patients who never had a shockable rhythm. The cause of this is unclear, but important confounding differences between cohorts in CPR protocol, unmeasured demographic factors, or postresuscitation care also cannot be ruled out. Based on these data, in facilities where ACLS is already available within 3 minutes of cardiac arrest, it is difficult to justify the considerable investment in equipment and education required when changing from manual defibrillators to AEDs for the treatment of in-hospital cardiac arrest.

Table 6. Survival by location

	Standard	Automated External Defibrillator	p
Initial VT/VF			
All locations	12/42 (29%)	14/45 (31%)	0.80
Intensive care unit	3/16 (19%)	5/17 (29%)	0.69
Stepdown	4/7 (57%)	3/11 (27%)	0.33
General ward	2/9 (22%)	2/9 (22%)	1.00
Emergency room	3/4 (75%)	2/3 (67%)	1.00
Operating room/recovery room	0/1 (0%)	0	
Cardiac catheterization/electrophysiology lab	0/4 (0%)	2/5 (40%)	0.44
Other	0/1 (0%)	0	
Location other than intensive care unit	9/26 (35%)	9/28 (32%)	0.85
Stepdown + general ward	6/16 (38%)	5/20 (25%)	0.48
Initial AS/PEA			
All locations	53/235 (23%)	36/239 (15%)	0.04
Intensive care unit	18/86 (21%)	10/94 (11%)	0.06
Stepdown	10/47 (21%)	11/38 (29%)	0.41
General ward	8/67 (12%)	7/78 (9%)	0.56
Emergency room	6/14 (43%)	3/8 (38%)	1.00
Operating room/recovery room	6/8 (75%)	1/2 (50%)	1.00
Cardiac catheterization/electrophysiology lab	4/6 (67%)	4/14 (29%)	0.16
Other	1/7 (14%)	0/5 (0%)	1.00
Location other than intensive care unit	35/149 (23%)	26/145 (18%)	0.24
Stepdown + general ward	18/114 (16%)	18/116 (16%)	0.95
AS/PEA only			
All locations	47/181 (26%)	31/182 (17%)	0.04
Intensive care unit	17/68 (25%)	8/75 (11%)	0.02
Stepdown	8/34 (24%)	9/28 (32%)	0.45
General ward	7/51 (14%)	7/59 (12%)	0.77
Emergency room	5/12 (42%)	3/7 (43%)	1.00
Operating room/recovery room	5/6 (83%)	0	
Cardiac catheterization/electrophysiology lab	4/5 (80%)	4/10 (40%)	0.28
Other	1/5 (20%)	0/3 (0%)	1.00
Location other than intensive care unit	30/113 (27%)	23/107 (22%)	0.38
Stepdown + general ward	15/85 (18%)	16/87 (18%)	0.9
Late VT/VF			
All locations	6/54 (11%)	5/57 (9%)	0.68
Intensive care unit	1/18 (5.6%)	2/19 (11%)	1.00
Stepdown	2/13 (15%)	2/10 (20%)	1.00
General ward	1/16 (6.3%)	0/19 (0%)	0.46
Emergency room	1/2 (50%)	0/1 (0%)	1.00
Operating room/recovery room	1/2 (50%)	1/2 (50%)	1.00
Cardiac catheterization/electrophysiology lab	0/1 (0%)	0/4 (0%)	
Other	0/2 (0%)	0/2 (0%)	
Location other than intensive care unit	5/36 (14%)	3/38 (8%)	0.47
Stepdown + general ward	3/29 (10%)	2/29 (7%)	1.00
All patients			
All locations	65/277 (23%)	50/284 (18%)	0.09
Intensive care unit	21/102 (21%)	15/111 (14%)	0.17
Stepdown	14/54 (26%)	14/49 (29%)	0.76
General ward	10/76 (13%)	9/87 (10%)	0.58
Emergency room	9/18 (50%)	5/11 (45%)	0.81
Operating room/recovery room	6/9 (67%)	1/2 (50%)	1.00
Cardiac catheterization/electrophysiology lab	4/10 (40%)	6/19 (32%)	0.70
Other	1/8 (13%)	0/5 (0%)	1.00
Location other than intensive care unit	44/175 (25%)	35/173 (20%)	0.27
Stepdown + general ward	24/130 (18%)	23/136 (17%)	0.74

VT, ventricular tachycardia; VF, ventricular fibrillation; AS, asystole; PEA, pulseless electrical activity.

ACKNOWLEDGMENTS

The authors are grateful to Judith Boura, Mary Ellen Welling, and Cathy Ketchum for valuable assistance in data analysis, description of the AED educational program, and CPR data maintenance.

REFERENCES

1. 2005 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care, Part 3: Overview of CPR. *Circulation* 2005; 112:IV-12–IV-18
2. Weaver WD, Copass MK, Bufi D, et al: Improved neurologic recovery and survival after early defibrillation. *Circulation* 1984; 69: 943–948
3. Valenzuela TD, Roe DJ, Cretin S, et al: Estimating effectiveness of cardiac arrest interventions: A logistic regression survival model. *Circulation* 1997; 96:3308–3313
4. White RD, Asplin BR, Bugliosi TF, et al: High discharge survival rate after out-of-hospital ventricular fibrillation with rapid defibrillation by police and paramedics. *Ann Emerg Med* 1996; 28:480–485
5. Mosesso VN Jr, Davis EA, Auble TE, et al: Use of automated external defibrillators by police officers for treatment of out-of-hospital cardiac arrest. *Ann Emerg Med* 1998; 32: 200–207
6. The Public Access Defibrillation Trial Investigators. Public-access defibrillation and survival after out-of-hospital cardiac arrest. *N Engl J Med* 2004; 351:637–646
7. Capucci A, Aschieri D, Piepoli MF, et al: Tripling survival from sudden cardiac arrest via early defibrillation without traditional education in cardiopulmonary resuscitation. *Circulation* 2002; 106:1065–1070
8. 2005 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care, Part 5: Electrical Therapies. *Circulation* 2005; 112(suppl IV):IV-35–IV-46
9. van Alem AP, Vrenken RH, de Vos R, et al: Use of automated external defibrillator by first responders in out of hospital cardiac arrest: Prospective controlled trial [published correction appears in BMJ. 2004; 328: 396]. *BMJ* 2003; 327:1312
10. Sweeney TA, Runge JW, Gibbs MA, et al: EMT defibrillation does not increase survival from sudden cardiac death in a two-tiered urban–suburban EMS system. *Ann Emerg Med* 1998; 31:234–240
11. Groh WJ, Newman MM, Beal PE, et al: Limited response to cardiac arrest by police equipped with automated external defibrillators: Lack of survival benefit in suburban and rural Indiana—The police as responder automated defibrillation evaluation (PARADE). *Acad Emerg Med* 2001; 8:324–330
12. Stotz M, Albrecht R, Zwicker G, et al: EMS defibrillation-first policy may not improve outcome in out-of-hospital cardiac arrest. *Resuscitation* 2003; 58:277–282
13. Sayre MR, Evans J, White LJ, et al: Providing automated external defibrillators to urban police officers in addition to a fire department rapid defibrillation program is not effective. *Resuscitation* 2005; 66:189–196
14. Weil MH, Fries M: In-hospital cardiac arrest. *Crit Care Med* 2005; 33:2825–2830
15. Nadkarni VM, Larkin GL, Peberdy MA, et al: First documented rhythm and clinical outcome from in-hospital cardiac arrest among children and adults. *JAMA* 2006; 295:50–57
16. Herlitz J, Aune S, Bang A, et al: Very high survival among patients defibrillated at an early stage after in-hospital ventricular fibril-

lation on wards with and without monitoring facilities. *Resuscitation* 2005; 66:159–166
17. Spearpoint KG, McLean CP, Zideman DA: Early defibrillation and the chain of survival in in-hospital adult cardiac arrest; minutes count. *Resuscitation* 2000; 44:165–169
18. Chan PS, Krumholz HM, Nichol G, Nallamothu BK; American Heart Association National Registry of Cardiopulmonary Resuscitation Investigators. Delayed time to defibrillation after in-hospital cardiac arrest. *N Engl J Med* 2003; 358:9–17
19. Destro A, Marzaloni M, Sermasi S, et al: Automatic external defibrillators in the hospital as well? *Resuscitation* 1996; 31:39–44
20. Hanefeld C, Lichte C, Mentges-Schroter I, et al: Hospital-wide first-responder automated external defibrillator programme: 1 year experience. *Resuscitation* 2005; 66:167–170
21. Gombotz H, Weh B, Mitterndorfer W, et al: In-hospital cardiac resuscitation outside the ICU by nursing staff equipped with automated external defibrillators—The first 500 cases. *Resuscitation* 2006; 70:416–422
22. Zafari AM, Zarter SK, Heggen V, et al: A program encouraging early defibrillation results in improved in-hospital resuscitation efficacy. *J Am Coll Cardiol* 2004; 44:846–852
23. Jacobs I, Nadkarni V, Bahr J, et al; International Liaison Committee on Resuscitation; American Heart Association; European Resuscitation Council; Australian Resuscitation Council; New Zealand Resuscitation Council; Heart and Stroke Foundation of Canada; InterAmerican Heart Foundation; Resuscitation Councils of Southern Africa; ILCOR Task Force on Cardiac Arrest and Cardiopulmonary Resuscitation Outcomes. Cardiac arrest and cardiopulmonary resuscitation outcome reports: Update and simplification of the Utstein templates for resuscitation registries: A statement for healthcare professionals from a task force of the International Liaison Committee on Resuscitation (American Heart Association, European Resuscitation Council, Australian Resuscitation Council, New Zealand Resuscitation Council, Heart and Stroke Foundation of Canada, InterAmerican Heart Foundation, Resuscitation Councils of Southern Africa). *Circulation* 2004; 110:3385–3397
24. Cummins RO, Chamberlain DA, Hazinski MF, et al: Recommended Guidelines for Reviewing, Reporting, and Conducting Research on In-Hospital Resuscitation: The In-Hospital 'Utstein Style': A Statement for Healthcare Professionals From the American Heart Association, the European Resuscitation Council, the Heart and Stroke Foundation of Canada, the Australian Resuscitation Council, and the Resuscitation Councils of Southern Africa. *Circulation* 1997; 95:2213–2239
25. Kellerman AL, Hackman BB, Somes G, et al: Impact of first-responder defibrillation in an urban emergency medical services system. *JAMA* 1993; 270:1708–1713
26. Bobrow BJ, Clark LL, Ewy GA, et al: Minimally interrupted cardiac resuscitation by emergency medical services for out-of-hospital cardiac arrest. *JAMA* 2008; 299:1158–1165
27. Kudenchuk PJ, Cobb LA, Copass MK, et al: Transthoracic incremental monophasic vs. biphasic defibrillation by emergency responders (TIMBER): A randomized comparison of monophasic with biphasic waveform ascending energy defibrillation for the resuscitation of out-of-hospital cardiac arrest due to ventricular fibrillation. *Circulation* 2006; 114:2010–2008
28. Schneider T, Martens PR, Paschen H, et al: Multicenter, randomized, controlled trial of 150-J biphasic shocks compared with 200- to 360-J monophasic shocks in the resuscitation of out-of-hospital cardiac arrest victims. Optimized Response to Cardiac Arrest (ORCA) Investigators. *Circulation* 2000; 102:1780–1787
29. Martens PR, Russell JK, Wolcke B, et al: Optimal Response to Cardiac Arrest study: Defibrillation waveform effects. *Resuscitation* 2001; 49:233–243
30. van Alem AP, Chapman FW, Lank P, et al: A prospective, randomised and blinded comparison of first shock success of monophasic and biphasic waveforms in out-of-hospital cardiac arrest. *Resuscitation* 2003; 58:17–24
31. Morrison LJ, Dorian P, Long J, et al: Out-of-hospital cardiac arrest rectilinear biphasic to monophasic damped sine defibrillation waveforms with advanced life support intervention trial (ORBIT). *Resuscitation* 2005; 66:149–157
32. 2005 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care, Part 4: Adult Basic Life Support. *Circulation* 2005; 112:IV-19–IV-34