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Clinical paper

Association between bystander automated external defibrillator use and survival in witnessed out-of-hospital cardiac arrest: A nationwide observational study in South Korea



Jang Yeong Heo¹, Young Taeck Oh¹, Jae Hwan Kim¹, Chiwon Ahn^{*}, Mi Suk Yang, Chan Woong Kim, Sung Eun Kim

Abstract

Aim: Sudden cardiac arrest is a global health issue, with out-of-hospital cardiac arrest (OHCA) posing a major challenge. Bystander cardiopulmonary resuscitation (CPR) and automated external defibrillators (AEDs) improve survival and neurological outcomes. However, their actual usage involves numerous constraints. Therefore, to determine the association between bystander AED use and survival of patients with OHCA, we analyzed South Korea's national OHCA database.

Methods: This retrospective study included cases from the Korea Disease Control and Prevention Agency's Out-of-Hospital Cardiac Arrest Surveillance database from January 2016 to December 2021. Adult OHCA cases treated with bystander intervention were categorized into two groups, CPR with AEDs and without AEDs. Propensity score matching was employed to control for confounders and analyze bystander AED use's impact on survival to discharge and neurological outcomes.

Results: Of 182,508 OHCA cases, 35,840 met the inclusion criteria, with 234 (0.7%) receiving bystander CPR with AEDs. The survival rate to discharge in the AED and non-AED group was 46.6% and 23.0%, respectively. However, after adjusting for potential confounders, bystander AED use did not significantly affect survival to discharge (adjusted odds ratio [aOR] 1.01, 95% confidence interval [CI] 0.70–1.44) or favorable neurological outcomes (aOR 1.08, 95% CI 0.99–1.18).

Conclusion: Survival to discharge or favorable neurological outcomes of patients with OHCA managed using bystander-applied AEDs and those without showed no significant difference. Factors such as AED accessibility and bystander preparedness influence the impact of bystander AED use. Further research should optimize AED deployment and usage strategies to enhance patient survival rate.

Keywords: Automated external defibrillator, Out-of-hospital cardiac arrest, Bystanders, Cardiopulmonary resuscitation, Survival, Neurological outcomes

Introduction

Sudden cardiac arrest is a major global public health issue, with out-of-hospital cardiac arrest (OHCA) posing a significant challenge owing to the average global incidence of 55 cases per 100,000 person-years.¹ In South Korea, more than 30,000 people experience OHCA annually; however, survival rates remain low.²

Cardiopulmonary resuscitation (CPR) is the only treatment that significantly improves survival rates; its effectiveness is heavily dependent on how quickly it is initiated after cardiac arrest.^{3,4} Rapid intervention by bystanders, which significantly enhances survival and neurological outcomes, is crucial.^{5–8} Numerous studies have revealed the benefits of immediate bystander chest compressions, and automated external defibrillator (AED) use by bystanders increases survival rates.^{5–10}

^{*} Corresponding author at: Department of Emergency Medicine, College of Medicine, Chung-Ang University, 84 Heukseok-ro, Dongjak-gu, Seoul 06974, Republic of Korea.

E-mail addresses: bluethin@cau.ac.kr (Y.T. Oh), thesult@cauhs.or.kr (J.H. Kim), cahn@cau.ac.kr (C. Ahn).

¹ These authors contributed equally to this work.

<https://doi.org/10.1016/j.resuscitation.2024.110388>

Received 28 June 2024; Received in Revised form 26 August 2024; Accepted 30 August 2024

Although bystander AED use is critical, it involves several constraints. Previous studies in specific regions of the United States reported positive therapeutic outcomes from AED use managed by well-trained dispatchers and bystanders.⁵ However, in several areas and countries, bystander AED use is low, and practical applications face significant barriers. For instance, AEDs are not always available at the time of a cardiac arrest, leading to limited availability and accessibility.^{11–14} Furthermore, untrained or inexperienced individuals may hinder the actual use of AEDs due to operational unfamiliarity and fear.^{15,16} Consequently, some studies have limited their analyses to trained rescuers or specific locations; however, large-scale studies involving diverse populations are scarce, making verification of AED use outcomes in real-world OHCA scenarios challenging.

To address these gaps, our study analyzed the entire OHCA database of patients transported to hospitals by emergency medical services (EMSs) in South Korea and examined the bystander intervention extent across all populations without restrictions on location or rescue type. We analyzed the impact of bystander-applied AEDs on survival rates and neurological outcomes to provide a comprehensive understanding of bystander interventions' efficacy in improving the care for patients with OHCA.

Methods

Design and data collection

This was a retrospective analysis of the Korea Disease Control and Prevention Agency's Out-of-Hospital Cardiac Arrest Surveillance (OHCAS) database. The database includes approximately 30,000 annual cardiac arrest cases in public locations across South Korea from January 2016 to December 2021. This allowed for the evaluation of the cardiac arrest patterns and outcomes managed by EMS.

In South Korea, EMSs, managed by the regional fire headquarters, operate 24/7, dispatching ambulances to OHCAs and providing initial treatment, including CPR with AEDs.¹⁷ Advanced life support drugs are not administered during prehospital care.¹⁸ Information from the EMS is systematically relayed to hospitals. The OHCAS database compiles comprehensive data from the EMS and hospital records, ensuring adherence to international resuscitation guidelines. This includes details on emergency responses and outcomes, providing a robust foundation for analyzing immediate interventions' impact on survival and neurological outcomes.

Study population

From January 2016 to December 2021, the OHCAS registry recorded 182,508 OHCA cases. We included adult (age ≥ 18 years) OHCAs witnessed with bystander interventions, including CPR and AED use. Patients with do-not-resuscitate orders, those transferred to other healthcare facilities before admission, those with invalid prehospital data, and those with unknown final outcomes were excluded from the study. Based on bystander AED use, patients were categorized into two groups: CPR with AED use and CPR without AED use.

Variables

Several variables were evaluated, including pertinent information on patient demographics, such as age, sex, comorbidities, use of bystander interventions (CPR and AED), location of the arrest, cause of arrest, initial cardiac rhythm monitored during the prehospital inter-

val (non-shockable vs. shockable), and prehospital and in-hospital return of spontaneous circulation (ROSC) according to the Utstein style. AED use was defined as any instance where an AED device was attached to the patient, whether a shock was delivered or the device assessed the cardiac rhythm. Comorbidities present before the cardiac arrest, such as hypertension, diabetes mellitus, heart disease, renal disease, respiratory disease, stroke, and dyslipidemia, were defined based on the clinical diagnoses established by healthcare professionals before the cardiac event and recorded in the patient's medical history. Shockable rhythm was defined as the initial rhythm of pulseless ventricular tachycardia or ventricular fibrillation.

Data on in-hospital treatments, including percutaneous coronary interventions (PCIs), target temperature management (TTM), pacemakers, and extracorporeal membrane oxygenation (ECMO), were collected. In addition, we recorded ROSC, survival to hospital discharge, and Glasgow–Pittsburgh Cerebral Performance Category (CPC) scores to hospital discharge to assess neurological outcomes. CPC scores ranging from 1 to 2 indicate good neurological outcomes. Conversely, CPC scores ranging from 3 to 5 indicate poor neurological outcomes.

Outcome measures

The primary outcome was survival to discharge, characterized by the patient's normal discharge or transfer to another healthcare facility for ongoing care following acute treatment. The secondary outcome was a favorable neurological outcome (CPC 1–2).

Statistical analyses

The data were analyzed using Excel 2019 (Microsoft, Redmond, WA, USA) and R (version 4.3.1, The R Foundation for Statistical Computing, Vienna, Austria). Descriptive statistics were used to describe the baseline characteristics. For continuous variables, values are shown as the means $\pm$ standard deviations. Normally distributed variables were analyzed using the Student's *t*-test between groups. Categorical variables are expressed as frequencies and percentages. The chi-squared or Fisher's exact tests were used to analyze categorical variables using contingency tables.

Multivariate logistic regression analyses using the "enter" method were conducted to estimate the AED use effect size on survival to discharge or favorable neurological outcomes and to calculate the adjusted odds ratios (aORs) and 95% confidence intervals (CIs) after adjusting for potential confounders.

Since matching cannot be performed with missing values, all cases with missing data were excluded before matching. The propensity score matching (PSM) model was developed using only variables without missing values. PSM was used to balance the observed co-variables between the two treatment groups. We matched the propensity score for CPR with AED use versus CPR without AED use to determine AEDs' effects on the outcomes of patients with witnessed OHCA under an equivalent potential covariate distribution. To eliminate selection bias, propensity-matched samples were extracted for analysis. We used limited prehospital variables for PSM. To reduce the treatment effect's standard error, we implemented many-to-one matching (1:1, 2:1, and 3:1) based on the propensity score because of the significant number of participants who did not use AEDs. This matching resulted in 234 patients in the 1:1 cohort, 468 patients in the 2:1 cohort, and 702 patients in the 3:1 cohort. Propensity scores were computed to 10 decimal places. The closest non-exposure group members in each model were matched to patients in the AED use group (exposure group)

with a propensity score difference threshold of less than 1×10^{-9} . No recurrence was observed in non-exposure cases. The AED use proportion among all eligible patients was a determining factor in the number of propensity-matched samples. For the total and PSM cohorts, the aORs with 95% CIs were calculated for the exposure variable. In the PSM cohorts, both OR and aOR were calculated to evaluate the effect of AED use on survival to discharge and favorable neurological outcomes.

Ethics statement

This study was exempted from review by the Institutional Review Board of Chung-Ang University Hospital because the study data were anonymous (2403-002-19512).

Results

Demographic findings

Between January 2016 and December 2021, 38,759 witnessed OHCA with bystander CPR were observed in the OHCA surveillance 2016–2021 in South Korea. We excluded 2,919 individuals from the population, including 1,389 cases with invalid prehospital data, 397 patients with unknown final outcomes due to being transferred to other facilities, 549 patients aged < 18 years, and 584 with do-not-resuscitate orders. Of the remaining 35,840 patients, 234 (0.7%) received bystander CPR with AEDs and 35,606 (99.3%) received CPR without AEDs (Fig. 1). The demographic and arrest characteristics of the study population are summarized in Table 1.

The bystander CPR with AED use group exhibited significant differences in several variables compared with the bystander CPR without AED use group. The bystander CPR with AED group had a

significantly higher proportion of male patients (81.2% vs. 65.1%, $p < 0.001$). The median age of the bystander CPR with AED use group was 59.0 (48.0–68.0) years, while that of the bystander CPR without AED group was 69.0 (56.0–80.0) years ($p < 0.001$). Additionally, the bystander CPR and AED group had significantly higher pre-hospital ROSC (46.6% vs. 16.5%, $p < 0.001$), public place where the cardiac arrest occurred (60.3% vs. 14.8%, $p < 0.001$), non-traumatic arrest cause (92.7% vs. 86.3%), and shockable rhythm (61.4% vs. 29.2%) than the bystander CPR without AED group.

A total of 109 (46.6%) and 8,172 (23.0%) patients in the bystander CPR with AED and the bystander CPR without AED use groups, respectively, were discharged alive. Favorable neurological outcomes were observed in 81 (26.2%) patients in the bystander CPR with AED group and 2,919 (11.6%) patients in the bystander CPR without AED group.

Univariate and multivariate analysis

Factors affecting survival to discharge for the bystander CPR population included sex (male), age, bystander AED use, public place where the cardiac arrest occurred, non-trauma arrest causes, and prehospital ROSC. After adjustment, bystander AED use and public place where the cardiac arrest occurred were factors that did not affect survival to discharge (aOR 1.01, 95% CI 0.70–1.44 and aOR 1.08 95% CI 0.99–1.18, respectively) (Supplementary Table S1).

Factors affecting favorable neurological outcomes for the bystander CPR population included sex (male), age, bystander AED use, public place where the cardiac arrest occurred, non-trauma arrest causes, and prehospital ROSC. After adjustment, the factor bystander AED use did not affect favorable neurological outcome (aOR 1.08 95% CI 0.99–1.18) (Supplementary Table S1).

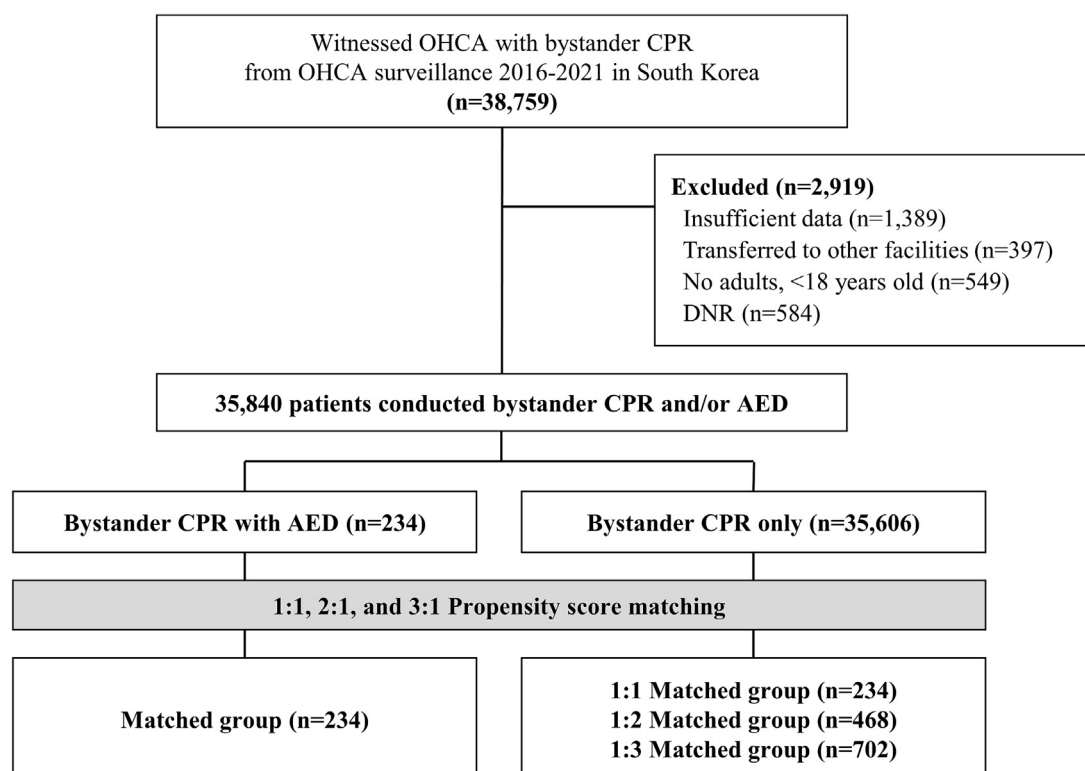


Fig. 1 – Flow diagram of the population. DNR, do-not-resuscitate; OHCA, out-of-hospital cardiac arrest.

Table 1 – Characteristics of the study population.

Variables	Bystander CPR with AED use (N = 234)	Bystander CPR without AED use (N = 35,606)	p-value
Sex, male	190 (81.2%)	23,171 (65.1%)	< 0.001
Age (years)	59.0 (48.0–68.0)	69.0 (56.0–80.0)	< 0.001
Insurance			0.640
National health insurance	207 (92.4%)	30,861 (90.4%)	
Medical aid	17 (7.6%)	3,152 (9.2%)	
Other	0 (0.0%)	122 (0.4%)	
Prehospital ROSC	109 (46.6%)	5,864 (16.5%)	< 0.001
Arrest location, public place	141 (60.3%)	5,254 (14.8%)	< 0.001
Arrest cause, non-traumatic	217 (92.7%)	30,724 (86.3%)	0.006
Disease	205 (94.5%)	28,379 (92.4%)	0.301
Shockable rhythm	70 (61.4%)	4,484 (29.2%)	< 0.001
Underlying disease			
Hypertension	89 (38.0%)	13,202 (37.1%)	0.815
Diabetes mellitus	53 (22.6%)	8,352 (23.5%)	0.831
Heart disease	45 (19.2%)	6,555 (18.4%)	0.812
Renal disease	7 (3.0%)	2,360 (6.6%)	0.036
Respiratory disease	4 (1.7%)	2,461 (6.9%)	0.003
Stroke	16 (6.8%)	3,132 (8.8%)	0.348
Dyslipidemia	20 (8.5%)	1,558 (4.4%)	0.003
PCI	89 (38.0%)	4,699 (13.2%)	< 0.001
TTM	21 (9.0%)	2,359 (6.6%)	0.191
Mechanical CPR	25 (10.7%)	4,394 (12.3%)	0.504
ECMO CPR	7 (3.0%)	788 (2.2%)	0.560
ROSC	151 (64.5%)	19,074 (53.6%)	0.001
Survival to discharge	109 (46.6%)	8,172 (23.0%)	< 0.001
Favorable neurological outcome	81 (36.2%)	3,919 (11.6%)	< 0.001

Abbreviations: AED, automated external defibrillator; CPR, cardiopulmonary resuscitation; ECMO, extracorporeal membrane oxygenation; PCI, percutaneous coronary intervention; ROSC, return of spontaneous circulation; TTM, target temperature management.

Propensity score-matched analysis

We extracted the PSM cohort. Because the bystander CPR without AED group was large, we used many-to-one matching (1:1, 2:1, and 3:1) on the propensity score to reduce the treatment effect's standard error. There were 234, 468, and 702 patients in the each matching group, respectively. The bystander CPR with AED use and without AED use groups showed a well-balanced distribution of demographics and most risk factors (Table 2).

In the PSM cohort, there was no statistically significant difference between the bystander CPR with AED use and bystander CPR without AED use groups for survival to discharge (odds ratio [OR] 0.98, 95% CI 0.54–1.79 in the 1:1 PSM cohort; OR 0.98, 95% CI 0.58–1.64 in the 2:1 PSM cohort; OR 0.82, 95% CI 0.51–1.34 in the 3:1 PSM cohort) and favorable neurological outcomes at discharge (OR 1.04, 95% CI 0.57–1.89 in the 1:1 PSM cohort; OR 1.17, 95% CI 0.71–1.94 in the 2:1 PSM cohort; OR 1.26, 95% CI 0.78–2.05 in the 3:1 PSM cohort) (Table 3). Additionally, the OR and aOR of several factors affecting the outcomes for each PSM cohort are shown in Supplementary Table S2.

Discussion

The findings of this investigation challenge the widely held assumption that bystander use of AEDs unequivocally enhances survival outcomes in witnessed OHCA situations. Despite expectations, our analysis revealed no significant advantage in survival to discharge

or favorable neurological outcomes for patients who received bystander-initiated AED application compared with those who did not. Additionally, because of the relatively small number of AED users, PSM was used to select multiples for the control group; however, it did not yield significant results. These results differ from those of previous studies, and it is necessary to determine whether they reflect actual AED usage in the real world. It is important to consider whether the AED was used correctly in patients who required it, whether there were any operational issues with the AEDs, or whether there was a significant delay in applying the AED. Compared to other studies in which the environment and participants were well controlled, in this study, various factors might have influenced AED usage, potentially leading to outcomes that differed from the hypothesis. These results may have been influenced by the complex interactions of various factors, including the timeliness of AED application, training and preparedness of laypersons, and AED availability in public places. Therefore, while the initial hypothesis anticipated a clear benefit from bystander AED use, the actual impact appeared to be more nuanced, indicating the need for a deeper exploration of the contexts and conditions under which bystander AED intervention is most beneficial.

Our findings suggest that the real-world application of AEDs is influenced by a range of factors beyond mere availability, including public awareness, training adequacy, and the accessibility of AEDs. The lack of significant difference in outcomes between AED and non-AED groups highlights the need for a comprehensive approach to improve bystander intervention readiness and AED usage. This

Table 2 – Demographics and outcomes in the propensity score-matched cohorts.

Variables	Bystander CPR and AED use (N = 234)	SMD Prematch	Bystander CPR without AED use					
			3:1 PSM (n = 702)	SMD Postmatch	2:1 PSM (n = 468)	SMD Postmatch	1:1 PSM (n = 234)	SMD Postmatch
Sex, male	190 (81.2%)	0.413	587 (83.6%)	−0.040	391 (83.5%)	−0.044	191 (81.6%)	0.022
Age (years)	59.0 [48.0–68.0]	−0.584	59.0 [49.0–69.0]	0.076	59.0 [49.0–68.5]	0.087	59.0 [48.0–68.0]	0.073
Insurance		−0.087		0.022		0.025		0.000
National health insurance	207 (92.4%)		616 (92.1%)		406 (90.0%)		202 (90.2%)	
Medical aid	17 (7.6%)		52 (7.8%)		44 (9.8%)		22 (9.8%)	
Other	0 (0.0%)		1 (0.1%)		1 (0.2%)		0 (0.0%)	
Prehospital ROSC	109 (46.6%)	0.604	338 (48.1%)	0.034	224 (47.9%)	0.051	111 (47.4%)	0.034
Arrest location, public place	141 (60.3%)	0.930	426 (60.7%)	0.006	284 (60.7%)	−0.009	141 (60.3%)	−0.009
Arrest cause, non-traumatic	217 (92.7%)	0.248	645 (91.9%)	0.038	430 (91.9%)	0.074	217 (92.7%)	0.066
Disease	205 (94.5%)	0.240	593 (91.9%)	0.099	396 (92.1%)	0.117	199 (91.7%)	0.091
Shockable rhythm	70 (61.4%)	0.378	213 (61.9%)	0.006	145 (63.0%)	0.065	71 (61.7%)	0.168
Underlying disease								
Hypertension	89 (38.0%)	0.020	235 (33.5%)	0.062	157 (33.5%)	0.070	85 (36.3%)	0.097
Diabetes mellitus	53 (22.6%)	−0.019	152 (21.7%)	0.092	104 (22.2%)	0.077	53 (22.6%)	0.041
Heart disease	45 (19.2%)	0.021	133 (18.9%)	0.098	93 (19.9%)	0.092	44 (18.8%)	0.065
Renal disease	7 (3.0%)	−0.214	36 (5.1%)	0.033	24 (5.1%)	0.038	9 (3.8%)	0.075
Respiratory disease	4 (1.7%)	−0.401	30 (4.3%)	0.033	20 (4.3%)	0.017	7 (3.0%)	0.033
Stroke	16 (6.8%)	−0.078	34 (4.8%)	0.073	22 (4.7%)	0.068	11 (4.7%)	0.102
Dyslipidemia	20 (8.5%)	0.149	34 (4.8%)	0.051	25 (5.3%)	0.061	16 (6.8%)	0.092
PCI	89 (38.0%)	0.512	270 (38.5%)	0.021	173 (37.0%)	0.035	78 (33.3%)	0.035
TTM	21 (9.0%)	0.082	67 (9.5%)	0.100	46 (9.8%)	0.105	25 (10.7%)	0.105
Mechanical CPR	25 (10.7%)	−0.054	53 (7.5%)	−0.060	39 (8.3%)	−0.069	25 (10.7%)	−0.083
ECMO CPR	7 (3.0%)	0.046	18 (2.6%)	0.042	10 (2.1%)	0.038	7 (3.0%)	0.025
ROSC	151 (64.5%)	0.229	475 (67.7%)	−0.048	317 (67.7%)	0.018	159 (67.9%)	−0.035
Survival to discharge	109 (46.6%)	0.474	348 (49.6%)	−0.014	224 (47.9%)	0.021	111 (47.4%)	0.000
Favorable neurological outcome	81 (36.2%)	0.496	264 (39.3%)	0.054	169 (37.8%)	0.072	80 (35.9%)	0.045

Abbreviations: AED, automated external defibrillator; CPR, cardiopulmonary resuscitation; ECMO, extracorporeal membrane oxygenation; PCI, percutaneous coronary intervention; PSM, propensity-score matching; ROSC, return of spontaneous circulation; SMD, standardized mean differences; TTM, target temperature management.

Table 3 – Univariate and multivariate logistic regression analyses of bystander AED use on survival to discharge.

Variables / outcomes	OR ^a (95% CI)	aOR ^b (95% CI)
1:1 PSM cohort	0.97	0.98
Survival to discharge	(0.67–1.39)0.98	(0.54–1.79)1.04
Favorable neurological outcome	(0.67–1.44)	(0.57–1.89)
2:1 PSM cohort	0.95	0.98
Survival to discharge	(0.69–1.30)1.01	(0.58–1.64)1.17
Favorable neurological outcome	(0.72–1.41)	(0.71–1.94)
3:1 PSM cohort	0.89	0.82
Survival to discharge	(0.66–1.19)1.06	(0.51–1.34)1.26
Favorable neurological outcome	(0.77–1.45)	(0.78–2.05)

Abbreviations: aOR, adjusted odds ratio; CI, confidence interval; PSM, propensity-score matching; OR, odds ratio.

includes targeted public education campaigns and training programs that not only increase awareness but also enhance the confidence and ability of bystanders to use AEDs effectively.

Despite better outcomes in the raw data, our logistic regression analysis did not find a significant association between bystander

AED use and improved survival or neurological outcomes, likely due to unmeasured confounders. Factors such as the timing of AED application, the variability in bystander training and confidence, and regional differences in AED accessibility may have influenced these results. Additionally, differences in EMS response times, the

quality of CPR before AED use, and patient comorbidities could have further confounded the outcomes.

The demographic findings of our study provide insights into the characteristics of OHCA incidents in which bystander AEDs are utilized. Notably, the group receiving bystander CPR with AED use comprised individuals with a significantly lower median age than those who received only CPR. This observation may reflect younger individuals' greater likelihood of experiencing cardiac arrest in public settings where AEDs are more readily available, as supported by the higher incidence of arrest in public places within this group. Additionally, the rate of prehospital ROSC was notably higher among patients who received AED interventions, underscoring the potential of immediate defibrillation to positively influence short-term survival outcomes. These demographic differences highlight the importance of considering patient and incident characteristics when evaluating the effectiveness of AED use in public health strategies. Such insights suggest a critical need to enhance AED accessibility and bystander intervention readiness, particularly in environments frequented by younger populations, to leverage the lifesaving potential of timely defibrillation.

The involvement of trained bystanders in regional resuscitation interventions or local legislation may have influenced bystander resuscitation skills, which is crucial in determining the effectiveness of AED use. Hansen et al. demonstrated that AED use significantly improved survival rates and favorable neurological outcomes, emphasizing the importance of widespread public access to AEDs and robust training programs.⁵ Their study highlighted that, following a statewide educational intervention in resuscitation training, bystander CPR abilities, including AED use, were expected to improve, which could lead to better outcomes than in regions with less comprehensive training. This suggests that differences in outcomes between our study and theirs may be attributable to variations in bystander preparedness and the prevalence of AEDs in public spaces.

Several studies have shown improvements in bystander CPR skills and outcomes following mandated training.^{19,20} Li et al. reported that after governmental legislation mandating emergency training, 3.7% of citizens received such training, leading to significant improvements in bystander capabilities and a marked increase in AED usage, which reached 5.29%, positively affecting survival rates.⁷ This finding contrasts with our study, where bystander AED use was relatively low at less than 1%, which may partially explain why we did not observe a significant improvement in survival or neurological outcomes.

Nakahara et al. analyzed 8 years of OHCA data across Japan and found that bystander AED use was associated with higher survival rates.⁶ A notable difference between their study and ours is the significantly higher chest compression rate by bystanders in their cohort. In our study, the chest compression rate among all patients with OHCA was approximately 20%, whereas it approached 50% in Nakahara et al.'s study. This disparity in CPR quality could be a key factor influencing the different outcomes observed. Additionally, their study emphasized the positive impact of combined bystander and EMS defibrillation efforts, whereas our data faced challenges in precisely analyzing EMS defibrillation usage. However, it is evident that appropriate and timely use of both bystanders and EMS in defibrillation is crucial for achieving positive outcomes.

In contrast to these studies, the frequency of bystander AED use is relatively low. Ko et al. analyzed 870 OHCA cases in public places between 2013 and 2015 and found that only 33 cases involved

bystander defibrillation.²¹ Similarly, in our study, only 234 of the 35,840 cases involved bystander AED use. These low usage rates may reflect the limited availability of AEDs or gaps in public awareness and training. Although we analyzed all EMS data in Korea, the low AED use rate needs to be addressed to improve outcomes. According to Smith et al., various factors hinder AED use during OHCA, including limited knowledge and awareness, fear of causing harm, lack of confidence, high costs, inadequate maintenance, accessibility issues, insufficient training, legal concerns, poor EMS integration, demographic variations, and emotional stress among rescuers.²² These factors likely contribute to the lower bystander AED use in our study, and addressing them through targeted interventions could enhance the effectiveness of AEDs and improve survival rates.

Several studies have suggested the necessity for such improvements. Government-led emergency care education rates should increase steadily. To significantly improve OHCA survival rates, at least 15% of the population should receive CPR education.²³ Mandating CPR education for schoolchildren is more effective than relying on voluntary participation.^{24,25} In 2009, the Ministry of Education, Science, and Technology in Korea introduced a health curriculum, including CPR education for upper-grade elementary students, and numerous CPR training sessions have since been conducted.²⁶ While CPR education can significantly improve knowledge, attitude, self-efficacy, and confidence, periodic and repeated training is essential.²³ However, the quality of CPR and AED training can vary significantly depending on the instructor competencies and the educational materials used.²⁷ Our results indicate a considerable gap between education and actual AED applications and outcomes, underscoring the need for enhanced training methods that closely align with real-world demands. This discrepancy highlights the importance of not only training individuals but also ensuring that they are prepared to effectively use these skills in emergency situations. As we advance, it is crucial to bridge this gap by integrating more practical hands-on scenarios into CPR and AED training programs. Our study suggests a considerable gap between education, actual AED applications, and outcomes.

Moreover, while AEDs are being actively deployed, it is essential to analyze the various factors that limit their use. In South Korea, AEDs have been installed due to legal requirements, and the number of AEDs has increased rapidly following the implementation of AED law and Good Samaritan Law's.²⁸ Over the past decade, the number of installed AEDs has increased steadily by 5–30% annually, with 58,182 AEDs installed nationwide as of 2022. Oh et al. reported significant differences in AED usage rates by location, suggesting that legally designated AED installation sites may not be effective based on usage rates.²⁸ A previous *meta*-analysis highlighted that AED accessibility could affect OHCA survival rates.²⁹ Therefore, instead of merely focusing on deployment, it is necessary to revise the AED placement strategy based on its correlation with the actual OHCA incidence. Additionally, CPR training should strategically include content that addresses improving accessibility and overcoming barriers to AED use. Johnson et al. emphasized the importance of strategic placement and clear signage for AEDs to ensure that they are easily accessible and visible during emergencies.³⁰ They also highlighted the need for a comprehensive AED registry and regular maintenance to enhance AED usability and effectiveness in real-world cardiac arrest scenarios. Recent research on using drones to enhance AED accessibility could also be a potential method for improving bystander AED usage.^{31,32}

This study had some limitations. First, the study was retrospective in nature, relying on preexisting data from the OHCAS database, which may contain inaccuracies or inconsistencies in data recording. The retrospective design also introduces the potential for selection bias and recall bias, which could affect the reliability of the findings. Second, the sample size for bystander AED use was relatively small compared to the overall study population, potentially affecting the statistical power of the analysis. Third, the study did not account for all potential confounders, such as variations in EMS response times and regional differences in AED availability, which could have influenced the outcomes. Additionally, since matching cannot be performed with missing values, cases with missing data were excluded prior to PSM, potentially introducing bias if the excluded cases differed systematically from those included in the analysis. Fourth, although previous studies have indicated that AED use and OHCA characteristics during the COVID-19 period differed from those before the pandemic, this study had limitations in conducting additional analysis on the characteristics of pandemic OHCA patients due to the low frequency of bystander AED use (less than 1%) and the fact that it was not considered a major focus in the initial design. This issue requires further analysis in future research. Finally, the observational design of the study precluded the establishment of causal relationships, and further prospective studies with controlled interventions are needed to validate these findings.

In conclusion, this nationwide observational study in South Korea found no significant difference in survival to discharge or favorable neurological outcomes between patients with witnessed OHCA who received bystander-applied AEDs and those who did not. These findings suggest that while bystander AED use is crucial, its actual impact on survival outcomes may be influenced by various real-world factors, such as AED accessibility and bystander preparedness. Further research is needed to explore these factors and optimize AED deployment and usage strategies to enhance OHCA survival rates.

Funding

This research was supported by a grant of the Korea Health Technology R&D Project through the Korea Health Industry Development Institute (KHIDI), funded by the Ministry of Health & Welfare, Republic of Korea (grant number: RS-2024-00335936).

Informed consent statement

The requirement for informed consent was waived due to the retrospective nature of the data.

Institutional review board statement

This study was exempted from review by the Institutional Review Board of Chung-Ang University Hospital because the study data were anonymous (2403-002-19512).

CRedit authorship contribution statement

Jang Yeong Heo: Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Conceptualization. **Young**

Taeck Oh: Writing – review & editing, Writing – original draft, Validation, Investigation, Conceptualization. **Jae Hwan Kim:** Writing – review & editing, Writing – original draft, Validation, Formal analysis, Data curation, Conceptualization. **Chiwon Ahn:** Writing – review & editing, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Mi Suk Yang:** Writing – review & editing, Investigation. **Chan Woong Kim:** Writing – review & editing. **Sung Eun Kim:** Writing – review & editing.

Data availability statement

The datasets generated in this study are available from the corresponding author upon request.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Chiwon Ahn reports financial support was provided by Korea Health Industry Development Institute. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary material

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.resuscitation.2024.110388>.

Author details

Department of Emergency Medicine, College of Medicine, Chung-Ang University, Seoul 06974, South Korea

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