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Review

Lay rescuer use of automated external defibrillators in infants, children and adolescents: A systematic review

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Abstract

Importance: Automated external defibrillator (AED) use is increasing, but use in children is uncommon. A growing literature of use in children by lay rescuers warrants review.

Objective: A systematic review of AED effectiveness in children experiencing out-of-hospital cardiac arrest (OHCA).

Data Sources: PubMed, EMBASE, Cochrane Register of Controlled Trials.

Study Selection: Children, ages 0–18, experiencing OHCA with an AED applied by a lay rescuer. Control population: children with no AED application.

Data Extraction and Synthesis: Results are reported according to PRISMA guidelines. Two authors independently reviewed all titles and abstracts of references identified by the search strategy, then generated a subset which all authors reviewed.

Main Outcomes and Measures: Critical outcomes were survival with Cerebral Performance Category (CPC) 1–2 at hospital discharge or 30 days and survival to hospital discharge.

Results: Population: age categories: <1 year, 1–12 years, 13–18 years. Lay rescuer AED application resulted in improved survival with CPC 1–2 at hospital discharge or 30 days to hospital discharge in age groups 1–12 and 13–18 years (RR 3.84 [95 % CI 2.69–5.5], RR 3.75 [95 %CI 2.97–4.72]), respectively and hospital discharge in both groups(RR 3.04 [95 % CI 2.18–4.25], RR 3.38 [95 % CI 2.17–4.16]), respectively. AED use with CPR improved CPC 1–2 at hospital discharge and hospital discharge (RR 1.49 [95 % CI 1.11–1.97], RR 1.55[1.12–2.12]).

Conclusions: AED application by lay rescuers is associated with improved survival with a CPC of 1–2 at 30 days, and improved survival to hospital discharge for children 1–18 years. There are limited data for children < 1 year.

Keywords: Public access defibrillation, Out-of-hospital cardiac arrest, Defibrillation, Cardiopulmonary resuscitation, Children, Adolescent

Introduction

Out-of-hospital cardiac arrest (OHCA) affects approximately 6500 children <18 years of age in the United States annually.[1] Annual world-wide incidence for all ages <18 years is 7.2–8.7/100,000 children.[2–5] Survival to hospital discharge ranges from 6.5% for infants <1 year up to 21.2% for adolescents 13–18 years.[5] A primary respiratory etiology with a bradycardic rhythm underlies most of these arrests. However, an initial shockable rhythm of pulseless ventricular tachycardia or ventricular fibrillation accounts for up to 15% of these episodes.[2,5,6] Survival is consistently higher for children who experience an initial shockable rhythm and this is particularly true for adolescents who experience a witnessed cardiac arrest and receive a shock with an automated external defibrillator (AED).[7,8]

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Public access defibrillation (PAD) programs were first introduced in the 1980s and have since expanded throughout the rest of the world.[9] One randomized trial and three systematic reviews have demonstrated effectiveness of adult PAD programs with improved hospital discharge and favorable neurologic outcomes as well as cost effectiveness for adult populations.[10–14]

The American Heart Association (AHA) and the European Resuscitation Council (ERC) include the use of AEDs for all children in the algorithms to guide rescuers for out-of-hospital cardiac arrest.[15,16] But, there are very limited data to assess effectiveness in a young population. Use in pediatric OHCA has been noted to be infrequent.[17,18] However, along with increasing use and availability of AEDs for children, there has recently been a growing literature on the inclusion of children in PAD programs, thus, warranting a systematic review of the literature.

This systematic review was commissioned by the International Liaison Committee on Resuscitation (ILCOR) by the Pediatric Life Support Task Force to inform cardiac arrest guidelines.

Methods

The protocol was submitted to the International Prospective Register of Systematic Reviews (PROSPERO) on April 17, 2021, and approved on June 18, 2021 (CRD42021249326). In the original PROSPERO application, the proposal included patients <12 years. Because most of the papers reported data for patients 0–18, we extended the analysis to include the patient age group 13–18, adding 99 patients to the analysis. Similarly, we report the Cerebral Performance Category(CPC) rather than Pediatric Cerebral Performance Category as this was the only neurologic assessment reported. The checklist for Systematic Review, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Guidelines is also in the Supplementary Material.[19]

Inclusion criteria

Inclusion criteria included all children <18 years suffering a non-traumatic OHCA who had an AED applied by a lay rescuer. Exclusion criteria included an AED applied by first responders, EMS personnel or other health care providers. Only outcomes considered critical were included in the final analysis. Critical outcomes were (i) survival to hospital discharge and (ii) a Cerebral Performance Category (CPC) of 1–2 at either hospital discharge or 30 days after discharge. Outcomes were approved by the ILCOR Pediatric Advanced Life Support Task Force.

We included randomized controlled trials in humans (RCTs) and non-randomized studies (non-randomized controlled trials, interrupted time series, controlled before-and-after studies, cohort studies). All years and languages were included as long as there was an English abstract. Unpublished studies (e.g., conference abstracts, trial protocols) were excluded.

Search strategy and study selection

The search strategy was developed by an information specialist at the University of Iowa and approved by the senior author (DLA). Three databases (PubMed, EMBASE and Cochrane) were searched on January 25, 2021, and on November 3, 2021 and July 1, 2022. The search strategy is summarized in Appendix B. Two members of the writing group (DLA, JA) independently screened the titles and abstracts of all studies identified by this search. The entire writing group then reviewed all these to select the ones for final inclusion. All disagreements were resolved by discussion and consensus. Some papers met inclusion and exclusion criteria but required data were either missing or not reported in a manner suitable for analysis. For these papers, authors were contacted directly by email to request data.

Risk of bias

The risk of bias was independently assessed by two reviewers (DLA, JA) using the ROBINS-I tool for observational data or Rob-2 for randomized controlled trials. (No randomized trials were identified.) Risk of bias is reported at the trial levels rather than outcome. In the included studies, the risk of bias was judged the same across all outcomes.

Data synthesis

Studies were assessed by clinical criteria, i.e., participants, age, interventions (AED applied or shock received) and outcomes. We were unable to perform a meta-analysis as data were heterogenous and only from two sources. Based on data available in the published studies, specified subgroup analyses were conducted. The subgroups were based on age and included <1 year, 1–12 years and 13–18 years.

Confidence in evidence

The Grade of Recommendations Assessment, Development and Evaluation (GRADE) methodology was used to assess the certainty of the evidence.[20] Certainty of evidence was categorized as high, moderate, low, or very low certainty of evidence. GRADEPro (McMaster University 2020) was used to construct the GRADE Tables and supplied the relative risk.

Results

Our search strategy identified 1,161 unique articles of which 74 were selected for full text review. Of these, 4 satisfied all inclusion and exclusion criteria. (Fig. 1, Table 1) Three papers[18,21,22] were from the Cardiac Arrest Registry to Enhance Survival (CARES) database in the United States. The CARES data reported did not correspond to the PICOST question in a manner from which we could extract only the data regarding AED use alone, although AED use was included in all three analyses. After contacting the authors, the CARES registry supplied the requested raw data which included the total number of children who experienced a cardiac arrest reported in these three studies, the number who had an AED applied by a lay rescuer, and survival outcomes. We were able calculate the relative risk of survival from these data. There were several studies from the All-Japan Utstein Registry of Fire and Disaster Management Agency (Japan FDMA) with overlapping dates for data inclusion and differing inclusion criteria. The most time inclusive study was chosen to avoid duplication of data.[23] This study reported shock delivery rather than AED application. No RCTs were found (Table 1).

Risk of bias

The Risk of Bias was judged to be serious with respect to the potential for confounding and selection bias, and moderate for measure-

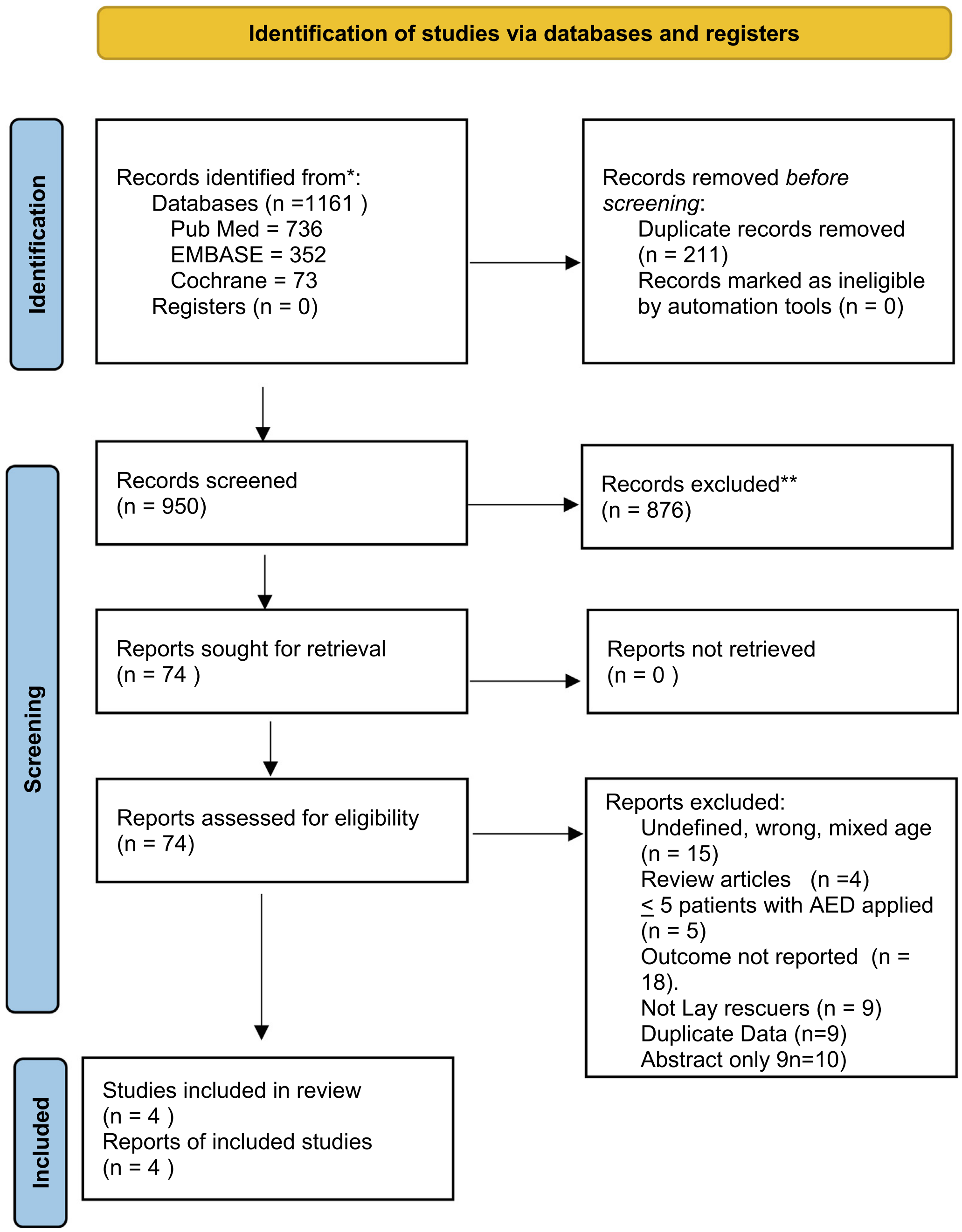

Fig. 1 – PRISMA diagram for study selection.

ment outcomes. (Table 2) Potential confounding factors included quality and type of CPR (compression only versus CPR with compressions and rescue breaths). Selection bias was considered to be serious as there was no indication why AEDs were applied in some but not all arrests. Measurement of outcomes was judged to be moderate, as reviewers for CPC assessments were not blinded to the intervention.

CPC of 1–2 at hospital discharge or 30 days

Three studies reported CPC value of 1–2 at hospital discharge[18,21,22] and one reported CPC 1–2 at 30 days after the event[23] although not within the same age groups. (Table 3A). For age groups >1 year, the RRs support application of an AED by a lay rescuer. The overall certainty of the evidence is judged to be very low.

The studies from the CARES Registry supplied data on children <1 year of age. (Table 3A) Only 12 children (0.3% of this age group) had an AED applied and only one was discharged with a CPC of 1–2. These data were judged insufficient to provide a conclusion.

Survival to hospital discharge

Three studies reported hospital discharge (Table 3B).[18,21,22] For children >1, the data support AED application by a lay rescuer. The overall certainty of the evidence was judged to be very low.

Table 1 – Included studies.

Study	Time of Patient Inclusion	Primary Inclusion Criteria	Study Design	Patients	Patient (Ages)	Intervention	Control	Risk of Bias
Naim 2017*	2013–2017	911 activated-non-traumatic arrests	Registry, Observational	3900	0–18 years	Lay rescuer AED application	No AED application	Serious
Kiyohara 2018	2005–2014	Confirmed arrest prior to EMS arrival	Registry, Observational	5899	6–17 years	Lay rescuer AED shock delivered	No AED shock	Serious
Naim 2019*	2013–2017	911 activated-non-traumatic arrests	Registry, Observational	7086	0–18 years	Lay rescuer AED application	No AED application	Serious
Griffis 2020*	2013–2017	911 activated-non-traumatic arrests	Registry, Observational	971	<18 years			

* Cumulative, raw data supplied directly from CARES Total patients = 7591.

Table 2 – Risk of bias assessment.

	Confounding	Selection	Classification of Intervention	Deviation from Intended Intervention	Missing Data	Measurement of Outcomes	Bias in Selection of Reported Results	Overall
CARES	Serious	Serious	Low	Low	Low	Moderate	Low	Serious
Japanese FDMA	Serious	Serious	Low	Low	Low	Moderate	Low	Serious

The data for infants < 1 year was the same for hospital discharge as it was for hospital discharge with a CPC of 1–2.

Association of bystander CPR with AED Use

The CARES registry provided data on the association of bystander CPR with AED use for both hospital discharge with CPC 1–2 and hospital discharge (Table 3C). These data were not stratified by age. For all ages, the RRs demonstrate that the bystander CPR with the addition AED application resulted in improved survival. The overall certainty of the evidence is judged to be very low.

Discussion

This systematic review from two large international population-based registries demonstrated that lay rescuer application of an AED in during pediatric OHCA resulted in statistically better outcomes for children >1 year of age. The association of CPR with the addition of the AED also resulted in improved survival. The certainty of evidence was very low. For children <1 there are extremely limited data.

Although this systematic review included only one study from the Japan FDMA, multiple studies evaluating the use of AEDs during pediatric OHCA have been published with overlapping time intervals and a variety of inclusion criteria[24–31] Population subsets included scholastic age categories,[29,30] arrests occurring only during school hours,[26] events witnessed by schoolchildren and classmates,[25] and location.[24] These studies demonstrate consistent results with improved one-month survival with favorable neurologic outcomes, regardless of inclusion criteria.

Cohort studies have been variable with respect to effectiveness at improving outcomes in children and adolescents. Several studies limited to school athletic facilities have shown improved survival in adolescents.[7,8] However, other cohort studies have not demonstrated improved survival with AED application.[32,33] The difficulty in interpreting these studies is that most are surveys, and suffer from inadequate response, selective recall, and selection bias. Additionally, these studies did not report outcome data other than survival and no denominator to assess risk ratios.

AEDs were first developed in the 1980s and the requirements of public access defibrillation programs were first outlined by the AHA in 1996.[33] At that time, they were approved only for adult use. The PAD Trial demonstrated improved survival compared to just bystander CPR[10] and multiple studies have since reported improved survival in adults with the addition of an AED to lay rescuer CPR. Recent systematic reviews demonstrated a 28% improvement in survival when an AED was used within 5 minutes of collapse,[11,13,14] while another demonstrated that cost-effectiveness for adults in settings of high cardiac arrest was < $100,000 per quality-adjusted life years.[12].

Shockable rhythms occur less frequently in pediatric OHCA arrest than during adult arrest, as pediatric arrests are more likely to have a primary respiratory etiology rather than a primary cardiac etiology. Estimated frequencies of shockable rhythms vary from

Table 3 – Survival outcomes of AED use.

Table 3A Survival with CPC 1–2 at hospital discharge or 30 days

Study	Age Groups	RR of CPC 1–2 (95% CI)
*CARES Registry		
	< 1 year	1.82 (0.28–11.96)
	1–12 Years	3.84 (2.69–5.5)
	13–18 years	3.75 (2.97–4.72)
#Japan FDMA	6–17 years	12.12 (17.12–94.97)

Table 3B Survival to Hospital Discharge

Study	Age Groups	RR of Survival (95% CI)
*CARES Registry		
	< 1 Year	1.82 (0.28–11.96)
	1–12 years	3.04 (2.18–4.25)
	13–18 years	3.38 (2.71–4.16)
#Japan FDMA	6–17 years	N/A

Table 3C Association of Bystander CPR with AED use, all ages

Study	Outcome	RR of Survival (95% CI)
CARES Registry	CPC 1–2 at Hospital Discharge	1.49 (1.11–1.97)
CARES Registry	Hospital Discharge	1.55 (1.12–2.12)

* AED application.
# AED shock.

7–15%.[2,6,18,23] In patients with a respiratory etiology, rescue breaths along with chest compressions demonstrate improved outcomes.[34,35] Thus, there is concern that application of an AED in pediatric arrest may delay initiation of CPR or increase pause duration of both compressions and rescue breaths. However, witnessed arrests in public locations are more likely to have primary cardiac etiology and associated shockable rhythms. In these cases, application of an AED by a lay rescuer is appropriate and likely to be beneficial. Additionally, lay rescuers have described use of the AED as a "calming influence", with the device acting somewhat as a team leader while providing instructions for the rescuers.[36] Moreover, at a time when AED use was increasing in Japan, outcomes in pediatric non-traumatic OHCA did not decline [23] Over the same time period, delivered shocks increased in patients aged 12–17 who suffered a OHCA of respiratory etiology, demonstrating that shockable rhythms can occur during arrests of non-cardiac origin.

Bystander CPR has been shown to improve hospital discharge outcomes in many but not all studies.[18,35,37,38] Bystander rates and outcomes are influenced by neighborhood characteristics, race/ethnicity, public vs private location, type of CPR, and dispatch assistance.[18,21,39] It is likely that lay rescuers who applied an AED were more highly trained and were also performing CPR while using the AED. We were concerned that the effect of the application of an AED could be more a function of CPR and CPR quality than of the AED itself. However, the association of bystander CPR with AED still predicted an improved outcome, indicating that the AED provides additional survival benefit.

Before AED use could be recommended for young children, confirmation of accurate rhythm identification and pediatric energy doses was essential, since the devices were initially evaluated and validated only in adults. Pediatric modifications with attenuated energy dosing were first approved in the United States in 2001. Three manufacturers have published high sensitivity and specificity analyses of specific pediatric rhythm detection algorithms[40] or validated adult algorithms in children[41,42] Energy dose is attenuated to approximately 50 Joules (J) without escalation. This dose provides from

2 J/kg to 10 J/kg for children weighing 5 to 25 kg. In 2003, ILCOR recommended AED use in children 1–8 years.[43] AED use is included for children by both the AHA and the ERC.[15,16] None of the publications in our review documented use of adult versus pediatric modifications, so it is unclear if there is a survival advantage to the pediatric modifications.

Use of an AED by a lay rescuer is highly dependent upon availability of a device and prior CPR training. In Japan, at least one AED had been installed in every elementary, middle/junior high school, and high school by 2015. Additionally, 90% of schools provided basic CPR and AED training to teachers and staff, along with a 33% overall increase in CPR training within the general population[24,44] This was associated with both increases in bystander CPR (44.4% in 2004 to 57.9% in 2015), shock delivery, and survival outcomes for all school-aged children (6–17) from 2005-2014.[23] The greatest improvement was noted in patients with a primary cardiac etiology in both age groups with an overall increase of 10.9% in 2005 to 29.9% in 2014.

In marked contrast, in the absence of concerted commitment and effort to increase CPR training and AED availability[24] bystander CPR and AED application for pediatric arrest demonstrate substantial underuse, similar to in adult OHCA.[9,45,46] Although ILCOR recommended development and implementation of adult PAD programs in 2015,[47] AEDs are applied prior to EMS arrival in < 3% of adult OHCA.[45,46]

In the studies included in this report, < 1–5% of victims had an AED applied or a shock delivered. Barriers to use include lack of recognition of cardiac arrest, availability of an AED, bystander awareness of AED location, bystander willingness to use the AED and operational status of the AED.[9] Within each of these categories, there are additional considerations specific to children including heightened anxiety associated with a pediatric arrest, uncertainty about appropriate use in a young child and confusion about how to the pediatric mode.[48] Although a discussion of methods to increase CPR and AED training is beyond the scope of this review, improving public awareness and preparedness, optimizing locations of AEDs, improving user-friendliness and AED signage are key to saving the lives of children and adults and are ripe areas for future reseach.[9]

Limitations

The conclusions of this review need to be interpreted in light of several considerations. The data are exclusively from two large population-based registries, and there are no controlled trials of AED use in children. The small proportion of children with cardiac arrest who had an AED applied may indicate that a selection bias existed among those who did and those who did not have an AED applied. Although guidelines recommend all children in cardiac arrest have an AED applied,[15,16] this is not routine at this time, even for EMS. The reasons for this are not apparent in this review, but likely are similar to those associated with the infrequent application of AEDs in adult cardiac arrest: unavailability and uncertainty about use. Another consideration of this review is the lack of information about the frequency of use of the pediatric modifications, specific rhythm detection algorithms, and energy attenuation.

Summary

AED application by lay rescuers is associated with survival to hospital discharge and improved survival with a CPC of 1–2 at 30 days for children > 1 year. This association persists even when CPR is provided. There is limited data on use in children < 1 year.

Conflicts of Interest

Dianne Atkins is compensated for her role as a member of the Pediatric Heart Network Data Safety and Monitoring Board. None of the trials within that network pertain to the subject of this study. None of the other authors declare a conflict of interest.

CRediT authorship contribution statement

Dianne L. Atkins: Conceptualization, Methodology, Supervision, Formal analysis, Writing – original draft, Visualization. **Jason Acworth:** Conceptualization, Methodology, Formal analysis. **Sung Phil Chung:** Methodology, Formal analysis, Visualization. **Amelia Reis:** Conceptualization, Methodology. **Patrick Van de Voorde:** Conceptualization, Methodology, Formal analysis.

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Appendix A. Members of the ILCOR Task Forces

Pediatric Life Support Task Force	Basic Life Support Task Force
Kee-Chong Ng (Chair)	Janet Bray (Chair)
Barney Scholefield (Vice – Chair)	Michael Smyth (Vice-Chair)
Richard Aickin (deceased)	Theresa Olasveengen
Jason Acworth	Maaret Castren
Thomaz Bittencourt Couto	
Allan de Caen	
Jana Djakow	Katie Dainty
Anne-Marie Guerguerian	Frederik Folke
Florian Hoffman	Carolina Malta
Monica Kleinman	Nicholas Johnson
David Kloeck	Takanari Ikeyama
Hiroshi Kurosawa	
Ian Maconochie	Anthony Lagina
Gabrielle NuthallSiobhan Masterson	
Tia Raymond	Ziad Nehme
Antonio-Rodriguez-Nunez	Chika Nishiyama
Steven Schexnayder	Tatsuya Noril
Janice Tijssen	Gavin Perkins
Alexis Topjian	Giuseppe Ristagno
	Federico Semeraro
	Christopher Smith
	Jane Wigginton

Appendix B. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.resplu.2022.100283.

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