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Clinical paper

Head and thorax elevation during cardiopulmonary resuscitation using circulatory adjuncts is associated with improved survival

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Abstract

Background: Survival after out-of-hospital cardiac arrest (OHCA) remains poor. A physiologically distinct cardiopulmonary resuscitation (CPR) strategy consisting of (1) active compression-decompression CPR and/or automated CPR, (2) an impedance threshold device, and (3) automated controlled elevation of the head and thorax (ACE) has been shown to improve neurological survival significantly versus conventional (C) CPR in animal models. This resuscitation device combination, termed ACE-CPR, is now used clinically.

Objectives: To assess the probability of OHCA survival to hospital discharge after ACE-CPR versus C-CPR.

Methods: As part of a prospective registry study, 227 ACE-CPR OHCA patients were enrolled 04/2019–07/2020 from 6 pre-hospital systems in the United States. Individual C-CPR patient data (n = 5196) were obtained from three large published OHCA randomized controlled trials from high-performing pre-hospital systems. The primary study outcome was survival to hospital discharge. Secondary endpoints included return of spontaneous circulation (ROSC) and favorable neurological survival. Propensity-score matching with a 1:4 ratio was performed to account for imbalances in baseline characteristics.

Results: Irrespective of initial rhythm, ACE-CPR (n = 222) was associated with higher adjusted odds ratios (OR) of survival to hospital discharge relative to C-CPR (n = 860), when initiated in <11 min (3.28, 95 % confidence interval [CI], 1.55–6.92) and < 18 min (1.88, 95 % CI, 1.03–3.44) after the emergency call, respectively. Rapid use of ACE-CPR was also associated with higher probabilities of ROSC and favorable neurological survival.

Conclusions: Compared with C-CPR controls, rapid initiation of ACE-CPR was associated with a higher likelihood of survival to hospital discharge after OHCA.

Keywords: Cardiac arrest, Cardiopulmonary resuscitation, Head up CPR, ACD-CPR, Active compression-decompression CPR, Impedance threshold device, ITD

Introduction

Conventional (C) cardiopulmonary resuscitation (CPR) performed in the flat and supine position has been the primary treatment for patients in cardiac arrest for decades.[1] In addition to rapid defibrillation in applicable cases, no other intervention has provided a greater impact on survival than C-CPR. Despite routine use of C-CPR, less than 10 % of patients with out-of-hospital cardiac arrest (OHCA) survive to hospital discharge and fewer with neurological recovery.[1]

A novel approach to resuscitation combining controlled elevation of the head and thorax with active compression decompression

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(ACD) CPR and an impedance threshold device (ITD) has shown to decrease intracranial pressure and improve cerebral perfusion pressure, cerebral blood flow and neurologically favorable survival in animal models.[2–7] ACD + ITD CPR is performed to preserve mean arterial pressure during gradual elevation of the head and thorax while gravity enhances venous return from the head and neck to the thorax and further lowers intracranial pressure.[2,4,5] This automated controlled elevation (ACE) CPR strategy consists of: (1) manual ACD-CPR and/or suction cup-based automated CPR; (2) an ITD; and (3) an automated controlled head and thorax patient positioning device (APPD).

Building upon pre-clinical work,[2–11] an APPD for controlled elevation of the head and thorax for patient use during CPR was developed and an ACE-CPR registry was established to track outcomes.[6,12] Initial analysis of this registry data showed rapid initiation of ACE-CPR was associated with a higher probability of return of spontaneous circulation (ROSC).[12] The objective of the current study was to assess if rapid implementation of ACE-CPR was associated with an increased likelihood of survival to hospital discharge following OHCA when compared with matched C-CPR controls from high-performing pre-hospital systems.

Methods

Study design and setting

Data in this multi-center observational study were prospectively collected from emergency medical services (EMS) systems that consistently implemented ACE-CPR as part of routine cardiac arrest care. These systems voluntarily contributed their OHCA data to the International Device Assisted Controlled Sequential Elevation CPR Registry, as previously described.[12] This registry was created to track clinical outcomes from agencies implementing ACE-CPR. Approved by the central WCG Institutional Review Board (study 1281307) with waiver of consent, de-identified patient data were sent periodically and securely to study staff.

Ten EMS systems contributed data. However, four of these systems were in the early phases of implementation and had not achieved routine and consistent use of ACE-CPR or tracking of data. Thus, data were analyzed from six EMS systems that consistently implemented ACE-CPR as part of their standard cardiac arrest care operating procedure.

ACE-CPR patients

The ACE-CPR study inclusion criteria were: (1) age $\geq$ 18 years; (2) OHCA, as defined by presence of ventricular fibrillation (VF) or ventricular tachycardia (VT), pulseless electrical activity (PEA), or asystole; (3) routine and consistent treatment with ACE-CPR within the participating pre-hospital system; and (4) routine and consistent recording of the 9–1–1 call receipt to placement of the APPD time interval. If a site routinely provided reports on adult pregnant patients, these patients were included. Prisoners were excluded.

C-CPR patients

C-CPR patient data were obtained using de-identified patient-level data from three large NIH-funded randomized controlled OHCA resuscitation trials: (1) Resuscitation Outcomes Consortium (ROC) Prehospital Resuscitation using an IMpedance valve and Early versus Delayed (PRIMED) Study,[13,14] (2) ROC Amiodarone, Lidocaine, or Placebo Study (ROC-ALPS),[15] and (3) Impact of an ITD and ACD-CPR on Survival from OHCA (ResQTrial).[16] Participating trial sites were selected, in part, based upon their record of C-CPR taught and performed according to American Heart Association Guidelines. These sites also had to meet quality CPR performance criteria before the patient enrollment could begin. C-CPR patients 18 years or older were included in the control population. Prisoners, women known to be pregnant, and patients without documentation of 9–1–1 call to start of EMS CPR time interval were excluded.

ACE-CPR training and use

Pre-hospital providers from participating registry sites were trained in ACE-CPR, which became their standard operating procedure. Providers were retrained periodically per local protocols. All ACE-CPR protocols included rapid initiation of manual CPR followed immediately by use of a manual ACD-CPR device (ResQPump™, ZOLL Medical) when available, placement of an automated external defibrillator (AED), initiation of ventilation with placement of an ITD (ResQPOD-16™, ZOLL Medical) on a facemask or airway adjunct, and rapid deployment of the APPD (EleGARD CPR™ Patient Positioning System, AdvancedCPR Solutions), applied in less than 6 seconds for minimal CPR interruption. An automated CPR device (LUCAS™ 2.0 or 3.0/3.1, Stryker Medical) was deployed per local protocols. Fig. 1 illustrates the elements of ACE-CPR. These devices are all cleared or approved for use in cardiac arrest by the U.S. Food and Drug Administration (FDA).

With ACE-CPR, rescuers were instructed to place the patient on the APPD while it was positioned in the lowest level, resulting in the immediate elevation of the patient's head and mid-thorax to 12 cm and 8 cm, respectively, relative to the horizontal plane. Rescuers performed CPR with the APPD in this position for 2 min to prime the circulatory system. Next, rescuers pushed a button on the APPD to raise the patient's head and torso during CPR over an additional 2-min period to a final head and thorax elevation of 22 cm and 9 cm, respectively. This approach of priming and gradual elevation was developed based on pre-clinical studies.[7] If used, the backplate of the automated CPR device was pre-attached to the APPD to mini-

Fig. 1 – Devices used to provide ACE-CPR: (1) an automated APPD to elevate the head and thorax, (2) a manual active compression-decompression CPR device and/or an automated CPR device attached to the PPD, and (3) an impedance threshold device that attaches to the airway. Abbreviations: CPR = cardiopulmonary resuscitation, APPD = automated patient positioning device, ACE-CPR = automated controlled elevation CPR.

mize CPR interruption, stabilize the automated mechanical CPR device, and reduce movement during CPR.

In some sites, the APPD was carried to the scene by a prehospital supervisor. In other sites, first responders carried it as part of the initial response to the arrest.

Study outcomes

The primary outcome was survival to hospital discharge. Secondary outcomes included ROSC at any time, and survival to hospital discharge with favorable neurological function. Favorable neurological function was defined using Cerebral Performance Category (CPC) score or modified Rankin Score (mRS).[17] From accepted practice, a CPC score of 1 or 2 was considered survival with neurologically favorable function and mRS scores $\leq$ 3 were considered as survival with neurologically favorable function.[17]

Statistical analysis

Summary statistics for baseline characteristics were reported as appropriate. Imbalance in baseline characteristics between C-CPR and ACE-CPR patients were assessed using standardized differences.[18] Unadjusted rates of primary and secondary study outcomes for ACE-CPR and C-CPR recipients were compared using crude odds ratios (OR) along with 95 % confidence intervals (CI).

To account for confounding effect modifiers by imbalance in baseline characteristics, we performed 9-1-1 call to start of CPR by EMS and propensity score-matched analyses.[19,20] A propensity score was first derived from a non-parsimonious multivariable logistic regression model predicting the receipt of ACE-CPR, with the following baseline characteristics as covariates: age, sex, EMS-witnessed arrest, bystander-witnessed arrest, bystander CPR attempt, and presenting shockable rhythm. Up to four C-CPR patients who had the nearest propensity score with caliper of 0.01 and the same discrete time interval from the 9–1–1 call to start of CPR by EMS were matched without replacement to each ACE-CPR recipient. This approach ensured that C-CPR patients would not be inadvertently matched with ACE-CPR recipients who already achieved ROSC.[21] The success of matching was evaluated further by checking for adequate overlap in propensity score between study groups and computing standardized differences for baseline characteristics. A standardized difference of 10 % or more after matching was considered indicative of residual imbalance in baseline characteristics.[18] The ORs of primary and secondary study outcomes were estimated using logistic regression. To account for a time-dependent relationship between the CPR methods and survival, ORs for ACE-CPR recipients relative to matched C-CPR recipients were stratified by 1-min increases in time from 9–1–1 to start of ACE-CPR. Time from 9–1–1 call to APPD device placement was used as a surrogate for the time from 9–1–1 to start of ACE-CPR.

In a pre-specified subgroup analysis, we investigated consistency of the association between ACE-CPR and survival to hospital discharge according to presenting rhythm. For this purpose, a first-order interaction involving presenting shockable rhythm and ACE-CPR was evaluated for statistical significance within the matched sample.

Two-sided P values of less than 0.05 were considered statistically significant. Statistical analyses were performed using Stata/SE Version 16.0 (Stata Corporation, College Station, TX, USA).

Results

Between April 2019 and July 2020, 409 patients from 10 EMS systems were treated with ACE-CPR and entered into the registry. Six of the 10 participating EMS systems contributed 227 patients meeting inclusion criteria with complete patient data (Fig. 2). ACE-CPR registry patients included in the analysis were younger, more likely to be male, but less likely to have bystander CPR than patients who were excluded. Included ACE-CPR patients were similar to those excluded in terms of time from 9–1–1 call to EMS CPR and 9–1–1 to ACE CPR, witnessed status, and initial rhythm (Supplementary Table 1).

For the C-CPR group, individual data were available for 5196 patients. Of these, 1179, 2728, and 1258 patients were from the ROC-PRIMED, ROC-ALPS, and ResQTrial studies, respectively (Fig. 2).

Characteristics of ACE-CPR and C-CPR patients are provided in Table 1. Most ACE-CPR patients presented with a non-shockable rhythm (83 %, 184/222). Among those presenting with VF/VT, 82 % (31/38) received at least one unsuccessful AED shock prior to PPD placement. Compared with C-CPR patients, ACE-CPR patients were less likely to have a bystander-witnessed cardiac arrest and fewer presented with an initial shockable rhythm, as the ROC-ALPS study only enrolled C-CPR patients with a shockable rhythm (Table 1 and Supplemental Table 2). Before propensity score matching, ACE-CPR patients had lower unadjusted probabilities of survival versus controls (Supplemental Table 2).

Of the 227 ACE-CPR patients that met inclusion criteria, 208 were matched for all baseline characteristics used for the propensity score analysis with 4C-CPR control patients (n = 832). A total of 5 ACE-CPR patients only matched with 3C-CPR controls (n = 15), 4 matched with only 2C-CPR controls (n = 8), and 5 matched with just 1C-CPR control(n = 5). No match was possible for 5 ACE-CPR patients. After matching, the sample consisted of 222 ACE-CPR and 860C-CPR patients and adequate overlap in propensity score was observed between study groups (Table 1). Matching was successful in attenuating imbalance in baseline characteristics, with standardized differences lower than 10 % for all variables (Table 1). After propensity score matching overall outcomes with ACE-CPR and C-CPR were comparable for the overall probabilities of ROSC (33 % [74/222] versus 33 % [282/860], OR, 1.02, 95 % CI, 0.75–1.49), survival to hospital discharge (9.5 % [21/222] versus 6.7 % [58/860], OR, 1.44, 95 % CI, 0.86–2.44) and survival to hospital discharge with favorable neurological status (5.9 % [13/222] versus 4.1 % [35/860], OR, 1.47, 95 % CI, 0.76–2.82), respectively, were similar. The epinephrine dose administered (mg) (IQR), though not one of the covariables used in the propensity analyses, was similar between the ACE-CPR and C-CPR groups before 3 (2–5) and 3 (3–4) and after propensity scoring 3 (2–4) and 3 (3–4), respectively (Supplemental Table 2).

Time from the 9–1–1 emergency call to placement of the PPD, a surrogate for the start of ACE-CPR, varied (Table 1). Before taking into consideration the impact of the 9–1–1 to start of ACE-CPR time interval, there were no significant differences in the primary or secondary endpoints between the propensity-matched ACE-CPR and C-CPR study groups.

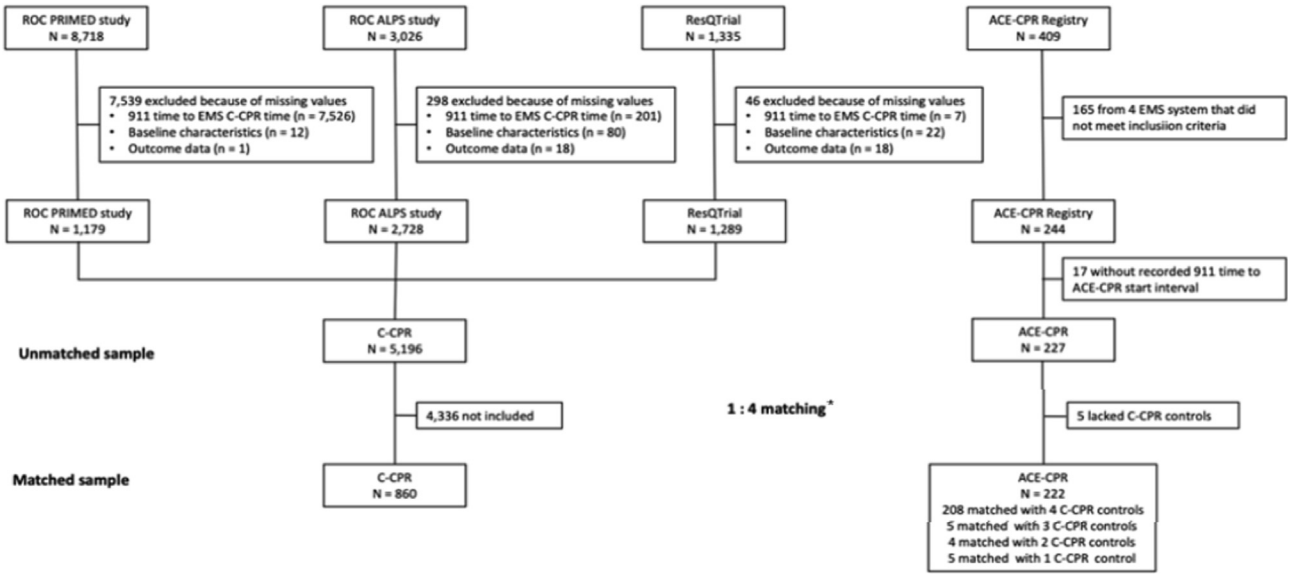

Fig. 2 – Study Flow Diagram. Conventional CPR control patients were selected from 3 published randomized clinical trials. The time from 9–1–1 call to placement of the automated head and thorax device was used as a surrogate for the 9–1–1 to ACE-CPR start interval. The EMS systems that contributed data to the ACE-CPR registry were located in (1) Edina, Minnesota; (2) Anoka County, Minnesota; (3) Germantown, Tennessee; (4) Little Rock, Arkansas; (5) Palm Beach County, Florida; and (6) Miami, Florida. Abbreviations: CPR = cardiopulmonary resuscitation, C-CPR = conventional CPR, EMS = emergency medical service, ACE-CPR = automated controlled elevation CPR. *Up to 1:4 matching for ACE-CPR to C-CPR patients was performed.

Table 1 – Comparison of baseline characteristics according to conventional versus automated controlled elevation cardiopulmonary resuscitation before and after matching.

	Before matching					After matching*				
Characteristic	C-CPR		ACE-CPR		Standardized difference, %	C-CPR		ACE-CPR		Standardized difference, %
No. patients	5196	...	227	...	...	860	...	222	...	...
Age, mean (standard deviation), years	64.8	(15.3)	64.2	(18.4)	3.5	65.7	(16.5)	64.2	(18.3)	8.2
Male sex, *n* (%)	3763	(72)	155	(68)	9.1	558	(65)	150	(68)	−5.7
EMS witnessed, *n* (%)	411	(7.9)	16	(7.0)	3.3	46	(5.4)	16	(7.2)	−7.6
Bystander witnessed, *n* (%)	2843	(55)	100	(44)	21.4	368	(43)	95	(43)	0.0
Bystander CPR attempt, *n* (%)	2436	(47)	98	(43)	7.4	354	(41)	95	(43)	−3.3
VF or pulseless VT, *n* (%)	3322	(64)	38	(17)	110	152	(18)	38	(17)	1.5
Time from 9–1–1 call to start of CPR by EMS, median (IQR), min	7	(6–10)	8	(6–10)	−2.0	8	(6–10)	8	(6–10)	−5.6
Time from 9–1–1 call to ACE device placement, median (IQR), min	...	...	15	(10–19)	...	...	...	15	(10–19)	...
Primary study, *n* (%)					...					...
ROC-PRIMED	1179	(23)	...	(...)		386	(45)	...	(...)	
AHUP			227	(100)		...	(...)	222	(100)	
ROC ALPS	2728	(52)	...	(...)		123	(14)	...	(...)	
ResQTrial	1289	(25)	...	(...)		351	(41)	...	(...)	
Propensity score, mean (standard deviation)	0.04	(0.04)	0.08	(0.03)	−110	0.08	(0.03)	0.08	(0.03)	−4.3

Abbreviations: ACE-CPR = automated controlled elevation cardiopulmonary resuscitation; C-CPR = conventional cardiopulmonary resuscitation; EMS = emergency medical services, IQR = interquartile range (25–75th percentiles), min = minutes.

* Propensity score analysis was performed to account for imbalances in baseline characteristics between C-CPR and ACE-CPR recipients. Up to four C-CPR recipients who had the nearest propensity score with caliper of 0.01 and the same discrete time interval from the 9–1–1 call to start of CPR by EMS were matched without replacement to each ACE-CPR recipient (See Methods).

Time from the 9–1–1 call to start of ACE-CPR was found to be a critical effect modifier of clinical outcomes in this study. Rapid initiation of ACE-CPR after 9–1–1 was associated with higher odds of survival to hospital discharge versus C-CPR matched patients (Fig. 3). When the 9–1–1 call to ACE-CPR start time was < 10 min, the OR of survival to hospital discharge for ACE-CPR was 3.72 (95 % CI: 1.57–

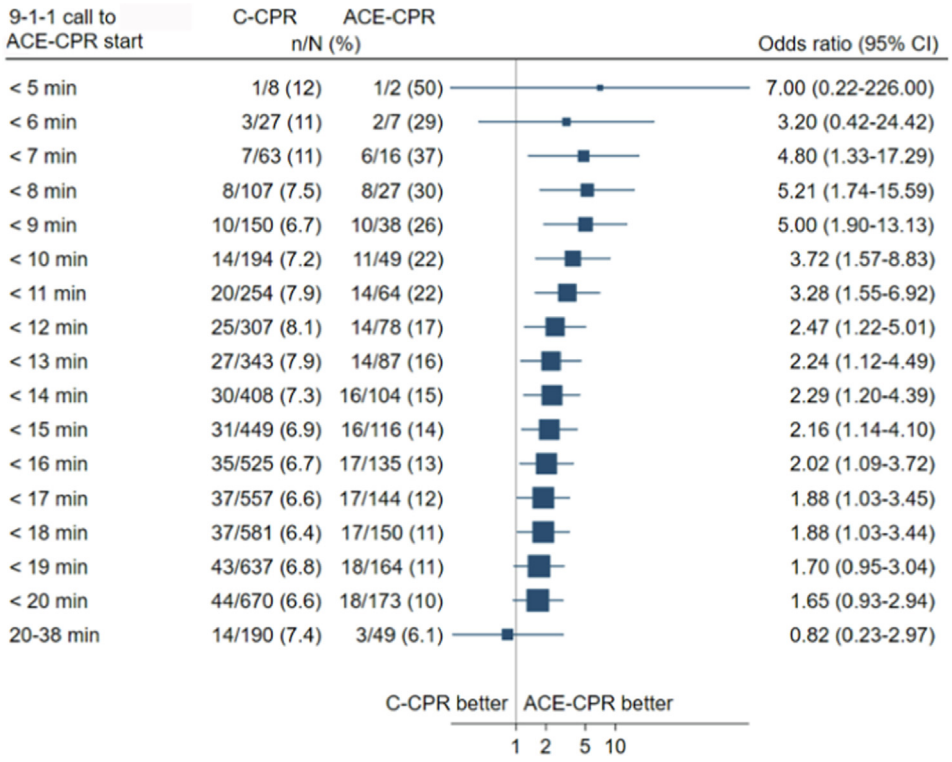

Fig. 3 – Forest-plot comparing odds of cumulative survival to hospital discharge between C-CPR and ACE-CPR according to time interval from the 9–1–1- emergency call to ACE-CPR start after propensity-score matching. Abbreviations: CPR = cardiopulmonary resuscitation, C-CPR = conventional-CPR, ACE-CPR = automated controlled elevation CPR, min = minutes.

8.83) versus C-CPR patients. ACE-CPR was associated with a higher probability of survival over a range of <7 min from for 9–1–1 to start of ACE-CPR (OR 4.8, 95 % CI, 1.33–17.29) to up to 18 min (OR 1.88, 95 % CI 1.03–3.44) versus matched C-CPR patients.

Treatment with ACE-CPR was also associated with higher probabilities of ROSC and survival to hospital discharge with favorable neurological function compared with C-CPR. The magnitude of these positive associations was again time-influenced and similar to what was observed for the primary outcome (Fig. 4, Supplemental Fig. 1). Rapid initiation of ACE-CPR was associated with higher adjusted odds of survival to hospital discharge with favorable neurological function compared with C-CPR patients (Fig. 4). When the EMS dispatch to ACE-CPR start time was <10 min, the OR was 3.07 (95 % CI: 1.10–8.52) for the ACE-CPR group versus C-CPR patients. ACE-CPR remained associated higher survival for EMS dispatch to CPR start intervals up to 18 min compared with matched C-CPR patients (OR: 2.21, 95 % CI: 1.07–4.57). Irrespective of the presenting rhythm, when ACE-CPR was started rapidly it was associated with higher probabilities of survival to hospital discharge versus C-CPR (Table 2).

Discussion

Results from this study found rapid application of ACE-CPR was associated with a higher probability of ROSC, survival to hospital discharge, and survival with favorable neurological function following OHCA versus matched C-CPR patients. When started in <10 min from the receipt of the 9–1–1 call, use of ACE-CPR was associated with nearly 4-fold higher odds of survival to hospital discharge versus propensity score matched C-CPR controls. This is the first clinical evidence of an association of ACE-CPR and improved survival to hospital discharge versus C-CPR, the standard of care for over 60 years.

These findings reinforce the importance of deploying ACE-CPR quickly. These time-dependent findings were consistent with other known time-sensitive cardiovascular emergencies in medicine, such as time from OHCA to start of CPR,[22,23] defibrillation,[24] or time to cardiac catheterization after myocardial infarction.[25,26] Importantly, since the median time from 9–1–1 call to first responder arrival in many emergency response systems across the U.S. is <7 min (6.3 min IQR 5.0–8.4),[27] providing rapid initiation of ACE-CPR is not only critical but achievable in most EMS systems.

The elements of ACE-CPR can be carried and applied by any trained first responder. This includes a spectrum of basic emergency medical personnel, including emergency medical technicians, firefighters, police, and lifeguards. The registry sites that utilized this frontline approach had the fastest application of ACE-CPR and best ROSC outcomes.[12] The sites with the best outcomes equipped first responders with just three separate bags or backpacks to facilitate device transport to the scene and to expedite initiation of ACD-CPR. These items included an AED, an automated suction-cup based CPR device, and a specially packed backpack that included the PPD, a resuscitator bag and facemask, a supraglottic airway,

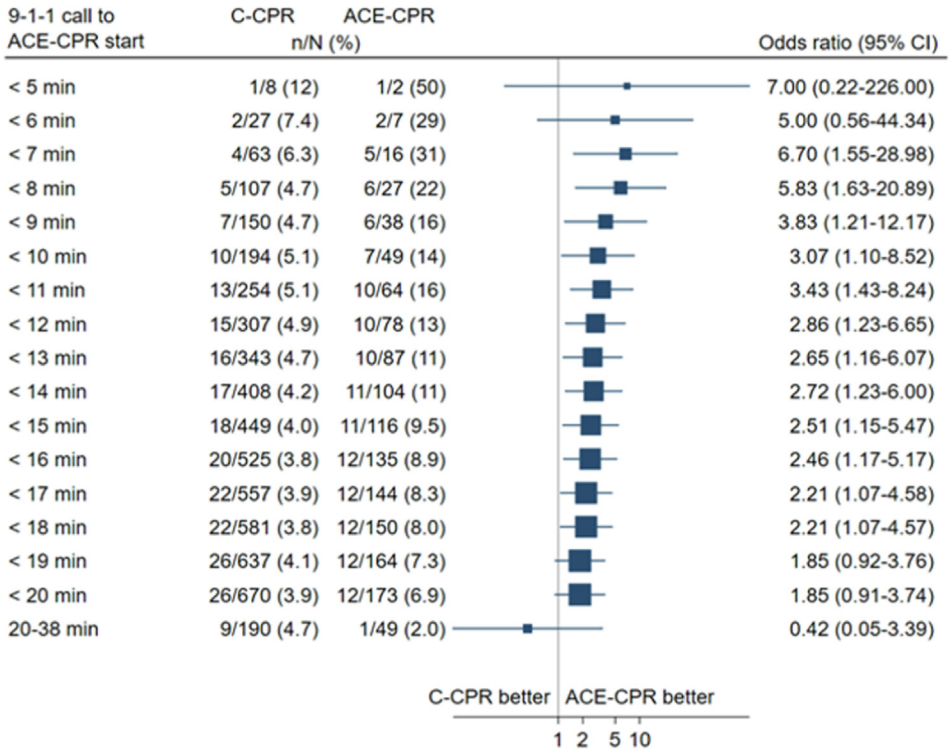

Fig. 4 – Forest-plot comparing odds of cumulative survival to hospital discharge with favorable neurological function between C-CPR and ACE-CPR according to time interval from the 9–1–1- emergency call to ACE-CPR start after propensity-score matching. Abbreviations: CPR = cardiopulmonary resuscitation, C-CPR = conventional-CPR, ACE-CPR = automated controlled elevation CPR, min = minutes.

and an ITD. Pragmatically, these results suggest that the fastest arriving responders should be prioritized to start ACE-CPR as soon as possible.

The association of ACE-CPR and a higher likelihood of survival to hospital discharge was consistent for OHCA patients with both initial shockable and non-shockable rhythms. This is important as the majority of cardiac arrests present with a non-shockable rhythm.[1] ACE-CPR can be used for the majority of adult cardiac arrest patients, with no known upper limit on age or co-morbidities, excluding a patient body habitus that would preclude device use. In general, patients weighing between 35 kg and 175 kg can be treated with the ACE-CPR devices described. To our knowledge, no significant adverse events have been reported specific to ACE-CPR.

The concept of "resuscitation time bias" must be considered. The longer the duration of cardiac arrest, the more likely a patient would receive ACE-CPR and longer cardiac arrest durations are associated with worse outcomes.[21] The impact of this potential confounder was reduced in this study since the exact time from 9–1–1 to start of EMS CPR was used to match patients. This eliminated a potential imbalance between study groups and reduced the likelihood that C-CPR treated patients would have had ROSC at the time ACE-CPR was initiated. Even though the 9–1–1 to start of ACE-CPR varied substantially from site to site, there was still a consistent clinical benefit from rapid initiation of ACE-CPR.[12] Another possible time bias is that patients who had ROSC after being shocked once did not receive ACE-CPR and were not enrolled, potentially biasing the results against ACE-CPR. Most ACE-CPR patients (n = 31/38, 82 %) enrolled with a presenting shockable rhythm had at least one failed shock prior to ACE-CPR start. The potential for imbalance of included C-CPR patients with a shockable rhythm being resuscitated after a single shock could not be eliminated with the study design, but that imbalance would have biased the study in favor of C-CPR.

Limitations should be considered. Data were observational, and a propensity score analysis was performed to account for potential imbalances in measured covariates from using a non-randomized study. Although conceptually there may be unknown confounding variables that were not considered in the propensity score analysis, 4:1 matching of baseline characteristics well-known to affect outcomes resulted in well-matched study groups. Additionally, data were obtained from early adopting sites that implemented ACE-CPR as part of routine cardiac arrest care. Thus, findings might be considered less generalizable. However, sites were geographically, sociologically, and operationally diverse. All sites implemented pre-arrival instructions, ACE-CPR re-training, quality assurance and improvement processes, and post-resuscitation care but protocols were not standardized. Nonetheless, with patients combined from multiple systems with a wide range of device implementation and deployment protocols, a large clinical benefit was still consistently observed with rapid ACE-CPR deployment. The relatively small sample size also posed a limitation, and these results should be confirmed in larger studies, particularly those that focus on rapid ACE-CPR deployment. An additional limitation is that pediatric patients <35 kg and morbidly obese patients weighing >175 kg, cannot currently be treated with ACE-CPR, and therefore excluded from this study.

These results reflect breakthroughs in the understanding of CPR physiology and how to optimize cardio-cerebral blood flow after cardiac arrest. ACE-CPR utilizes complementary mechanisms of action

Table 2 – Comparison of cumulative survival to hospital discharge between conventional and ACE-CPR according to initial recorded cardiac rhythm and start of ACE-CPR after propensity-score matching and matching for discrete time from 911 to CPR.

	Asystole/Pulseless Electrical Activity						Ventricular tachycardia/Ventricular Fibrillation						
9–1–1- call to ACE-CPR start interval*	C-CPR, *n/N* (%)		ACE-CPR, *n/N* (%)		Odds ratio of survival to discharge (95 % CI)		C-CPR, *n/N* (%)		ACE-CPR, *n/N* (%)		Odds ratio of survival to discharge (95 % CI)		*P* for interaction
<5 min	0/4	(0.0)	0/1	(0.0)	. . .	(. . .)	1/4	(25)	1/1	(100)	. . .	(. . .)	. . .
<6 min	0/15	(0.0)	0/4	(0.0)	. . .	(. . .)	3/12	(25)	2/3	(67)	6.00	(0.39–92.28)	. . .
<7 min	0/35	(0.0)	1/9	(11)	. . .	(. . .)	7/28	(25)	5/7	(71)	7.50	(1.18–47.68)	. . .
<8 min	0/71	(0.0)	2/18	(11)	. . .	(. . .)	8/36	(22)	6/9	(67)	7.00	(1.42–34.43)	. . . .
<9 min	0/106	(0.0)	4/27	(15)	. . .	(. . .)	10/44	(23)	6/11	(55)	4.08	(1.03–16.23)	. . . .
<10 min	3/142	(2.1)	4/36	(11)	5.79	(1.23–27.16)	11/52	(21)	7/13	(54)	4.35	(1.21–15.60)	0.78
<11 min	6/190	(3.2)	5/48	(10)	3.57	(1.04–12.23)	14/64	(22)	9/16	(56)	4.59	(1.45–14.53)	0.77
<12 min	7/235	(3.0)	5/60	(8.3)	2.96	(0.91–9.68)	18/72	(25)	9/18	(50)	3.00	(1.03–8.72)	0.99
<13 min	7/267	(2.6)	5/68	(7.3)	2.95	(0.91–9.60)	20/76	(26)	9/19	(47)	2.52	(0.89–7.10)	0.85
<14 min	8/320	(2.5)	7/82	(8.5)	3.64	(1.28–10.35)	22/88	(25)	9/22	(41)	2.08	(0.78–5.52)	0.44
<15 min	9/361	(2.5)	7/94	(7.5)	3.15	(1.14–8.69)	22/88	(25)	9/22	(41)	2.08	(0.78–5.52)	0.56
<16 min	11/425	(2.6)	7/110	(6.4)	2.56	(0.97–6.76)	24/100	(24)	10/25	(40)	2.11	(0.84–5.31)	0.78
<17 min	11/449	(2.5)	7/117	(6.0)	2.53	(0.96–6.87)	26/108	(24)	10/27	(37)	1.86	(0.76–4.55)	0.64
<18 min	11/469	(2.4)	7/122	(5.7)	2.53	(0.96–6.68)	26/112	(23)	10/28	(36)	1.84	(0.76–4.47)	0.68
<19 min	13/517	(2.5)	8/134	(6.0)	2.46	(1.00–6.07)	30/120	(25)	10/30	(33)	1.50	(0.63–3.56)	0.44
<20 min	14/546	(2.6)	8/142	(5.6)	2.27	(0.93–5.52)	30/124	(24)	10/31	(32)	1.49	(0.63–3.52)	0.51
≥20 min	5/162	(3.1)	3/42	(7.1)	2.42	(0.55–10.54)	9/28	(32)	0/7	(0.0)	. . .	(. . .)	. . .

Abbreviations: CI = confidence interval, C-CPR = conventional cardiopulmonary resuscitation, ACE-CPR = automated controlled elevation CPR, min = minutes.

* Time from emergency 9–1–1 call to automated patient positioning device placement was a surrogate for the 9–1–1 call to ACE-CPR start interval. The value for survival to hospital discharge was missing for two C-CPR individuals.

to improve pre-load, preserve coronary perfusion pressure, reduce intracranial pressure, enhance venous drainage from the head and neck, and improve cerebral blood flow. These respective mechanisms have been documented in previous translational studies to be inter-dependent, time dependent, and synergistic when combined with proper sequencing.[2–4,6–8] The association of ACE-CPR with improved outcomes could also be enhanced further by effective implementation of other elements of the chain of survival that precede initiation of CPR and follow ROSC, including definitive in-hospital treatment.[12,28,29]

Conclusions

Building upon prior investigations, the current study provides evidence of a strong positive association between rapid implementation of ACE-CPR and OHCA survival, with the potential to save more lives with technologies that any first responder can use. Confirmation of these findings in further studies is ongoing.

Conflict of interest

The following authors do not have any relationship with industry or other relevant entities, financial or otherwise that might pose a conflict of interest in connection with the submitted article: Moore, Pepe, Scheppke, Lick, Duval, Holley, Jacobs, Nystrom, Quinn, Adams, Hutchison, C Mason, Martinez, S Mason, Clift, Antevy, Coyle, Grizzard, Garay, Debaty, Crowe, Labarère. Salverda: Received payment from AdvancedCPR Solutions on contract basis for data collection services. Lurie: Co-founder of AdvancedCPR Solutions, owns a significant equity position in this company and serves as its Chief Medical Officer.

CRediT authorship contribution statement

Johanna C. Moore: Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Supervision, Visualization, Project administration, Funding acquisition. **Paul E Pepe:** Methodology, Writing – review & editing, Visualization. **Kenneth A. Scheppke:** Conceptualization, Investigation. **Charles Lick:** Conceptualization, Investigation. **Sue Duval:** Methodology, Formal analysis, Writing – review & editing. **Joseph Holley:** Investigation, Conceptualization. **Bayert Salverda:** Data curation, Project administration. **Michael Jacobs:** Conceptualization. **Paul Nystrom:** Conceptualization, Investigation. **Ryan Quinn:** Conceptualization, Investigation. **Paul J. Adams:** Investigation. **Mack Hutchison:** Investigation. **Charles Mason:** Investigation. **Eduardo Martinez:** Investigation. **Steven Mason:** Investigation. **Armando Clift:** Investigation. **Peter M. Antevy:** Investigation. **Charles Coyle:** Investigation. **Eric Grizzard:** Investigation. **Sebastian Garay:** Investigation. **Remle P. Crowe:** Validation, Methodology, Writing – review & editing. **Keith G Lurie:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Supervision, Visualization, Project administration, Funding acquisition. **Guillaume P. Debaty:** Conceptualization, Methodology, Visualization, Writing – review & editing. **José Labarère:** Methodology, Formal analysis, Writing – original draft, Writing – review & editing, Visualization.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.resuscitation.2022.07.039.

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