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Smartphone Activation of Citizen Responders to Facilitate Defibrillation in Out-of-Hospital Cardiac Arrest

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ABSTRACT

BACKGROUND Dispatching citizen responders through a smartphone application (app) holds the potential to increase bystander cardiopulmonary resuscitation (CPR) and defibrillation in out-of-hospital cardiac arrest (OHCA).

OBJECTIVES This study investigated arrival at the OHCA location of app-dispatched citizen responders before the Emergency Medical Services (EMS) and the association with bystander CPR and bystander defibrillation.

METHODS Suspected OHCAs with alerted citizen responders from September 1, 2017, to August 31, 2018, were included. Citizen responders located 1.8 km (1.1 miles) from the OHCA were dispatched to start CPR or retrieve an automated external defibrillator. OHCAs where at least 1 citizen responder arrived before EMS were compared with OHCAs where EMS arrived first. In both groups, random bystanders could be present before the arrival of citizen responders and the EMS. Primary outcomes were bystander CPR and bystander defibrillation, which included CPR and defibrillation by citizen responders and random bystanders.

RESULTS Citizen responders were alerted in 819 suspected OHCAs, of which 438 (53.5%) were confirmed cardiac arrests eligible for inclusion. At least 1 citizen responder arrived before EMS in 42.0% (n = 184) of all included OHCAs. When citizen responders arrived before EMS, the odds for bystander CPR increased (odds ratio: 1.76; 95% confidence interval: 1.07 to 2.91; $p = 0.027$) and the odds for bystander defibrillation more than tripled (odds ratio: 3.73; 95% confidence interval: 2.04 to 6.84; $p < 0.001$) compared with OHCAs in which citizen responders arrived after EMS.

CONCLUSIONS Arrival of app-dispatched citizen responders before EMS was associated with increased odds for bystander CPR and a more than 3-fold increase in odds for bystander defibrillation. (The HeartRunner Trial; NCT03835403) (J Am Coll Cardiol 2020;76:43–53) © 2020 The Authors. Published by Elsevier on behalf of the American College of Cardiology Foundation. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

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ABBREVIATIONS AND ACRONYMS

AED = automated external defibrillator

App = application

CPR = cardiopulmonary resuscitation

EMS = Emergency Medical Services

OHCA = out-of-hospital cardiac arrest

Publicly accessible automated external defibrillators (AEDs) are increasingly deployed in many countries, but bystander defibrillation occurs only in 2% to 9% of all out-of-hospital cardiac arrests (OHCAs) (1–4). This represents a major barrier to further improve survival after OHCA because early cardiopulmonary resuscitation (CPR) and defibrillation are 2 of the most important factors for improved survival (5,6). In Denmark, multiple initiatives have increased bystander CPR to 77%, and 9% of all patients with OHCA were defibrillated by bystanders before the arrival of the emergency medical services (EMS) in 2018 (4,7). However, Denmark has an established nationwide AED registry with nearly 20,000 AEDs registered in 2017 (350 AEDs/100,000 inhabitants) (8,9) and new initiatives to increase use of publicly accessible AEDs are needed to further improve bystander defibrillation chances and survival after OHCA.

SEE PAGE 54

The opportunity to activate volunteer citizens who are close to a cardiac arrest holds the potential to increase bystander CPR and defibrillation in both public and residential locations (10–14). Activation of citizen responders by text-messages or smartphone applications (apps) is becoming more widespread, but little is known about how and when citizen responder systems work most effectively. Accordingly, knowledge of the effect on patient outcome is warranted, underlined by the International Liaison Committee on Resuscitation and the American Heart Association (15,16). A citizen responder system using app-dispatch was implemented in the Capital Region of Denmark in September 2017 (catchment area of 1.8 million).

We hypothesized that when citizen responders arrived before EMS, a larger proportion of patients would receive bystander intervention (CPR and/or defibrillation) compared with those in which citizen responders did not arrive first. This prospective observational study investigated the association between arrival of citizen responders before EMS and bystander CPR and bystander defibrillation during the first year of implementation of a citizen responder system using a smartphone app. We also investigated self-reported physical injuries and psychological impact among activated citizen responders.

METHODS

STUDY SETTING AND DESIGN. In this prospective observational study, we analyzed consecutive OHCAs in which citizen responders were activated from September 1, 2017, to August 31, 2018, in the Capital Region of Denmark. The region comprises 1.8 million inhabitants and covers 2,559 km^2 including both urban and rural areas (17). Approximately 1,500 OHCAs occur every year, corresponding to 83 per 100,000 inhabitants (4). The Capital Region of Denmark is served by 1 emergency dispatch center and by a 2-tiered EMS system including an ambulance (basic life support) and a physician-staffed vehicle (advanced life support). The emergency dispatchers are instructed to guide callers to start CPR (dispatch-assisted CPR) and, when feasible, direct additional bystanders to retrieve the nearest accessible AED. Emergency dispatchers also can call the contact persons for nearby AEDs and encourage them to deliver the AEDs to the OHCA location. EMS personnel are obliged to complete prehospital medical records according to the Utstein criteria for OHCAs in which resuscitation has been initiated by bystanders or EMS or an AED has been used before EMS arrival (18). All report forms are reviewed for quality and accuracy of the data.

THE DANISH AED NETWORK. The Danish AED Network is a nationwide network that maps all voluntarily registered AEDs in Denmark with exact location and detailed information about accessibility (8,9). The network is linked to all emergency dispatch centers in Denmark and included approximately 5,000 AEDs (108 AEDs/100,000 inhabitants/1,000 km^2) in the Capital Region of Denmark at the beginning of the study period, with 32% of the AEDs accessible 24 h a day, 7 days a week (9).

THE CITIZEN RESPONDERS. A citizen responder is a person who voluntarily registers through the app. It is a requirement to be 18 years of age or older and CPR and/or AED training is highly recommended but not mandatory for registration. Recruitment of citizen responders started in July 2017 through social media, television commercials, and newspaper advertisements. By September 1, 1,030 citizen responders had registered and an additional 22,087 registered during the study period (1,284 citizen responders/100,000 inhabitants). Median age at registration was 34 years (Q_1, Q_3; 25, 46 years), 50.7% were male, and 26.0% were health care professionals. Of all citizen responders, 98.6% reported having received CPR training before registration.

THE CITIZEN RESPONDER SYSTEM. The citizen responder system is based on smartphone app technology (Heartrunner app) and is linked to the Danish AED Network. It was implemented at the emergency dispatch center covering the entire Capital Region of Denmark on September 1, 2017. In the event of

suspected OHCA, the emergency dispatch center activates the citizen responders along with the 2-tiered EMS system. The system identifies up to 20 citizen responders within a maximum radius of 1.8 km (corresponding to a response time of maximum 15 min with a default speed of 2 m/s [4.5 mph]). App adjustments during the study period are described in Supplemental Appendix 1. The emergency dispatchers are instructed not to activate citizen responders in cardiac arrests involving trauma, suicide, and children younger than 8 years, and in those occurring in nursing homes or in unsafe surroundings (Supplemental Appendix 2). Citizen responders who accept an alarm are dispatched to either go straight to the OHCA location and start/assist with CPR or to retrieve the nearest accessible AED. The app refers only to AEDs accessible at the time of the alarm using accessibility information from the AED Network (Supplemental Appendix 1).

SURVEY AND DEBRIEFING. Ninety minutes after an alarm, all activated citizen responders receive a link to an electronic survey by text message (Supplemental Appendix 3). A reminder is sent the following day in case of a missing response. Citizen responders are asked whether they arrived before EMS, if they performed CPR, applied an AED, and whether the AED delivered a shock. Finally, they report physical injuries and/or degree of psychological impact. Psychological impact is reported on a 5-level scale from not affected to severely affected. If citizen responders reported being severely affected, they were contacted and offered debriefing by health care personnel.

STUDY POPULATION. We included all suspected OHCAs in which citizen responders were activated from September 1, 2017, to August 31, 2018. We excluded cases that were not true cardiac arrests confirmed by the Danish Cardiac Arrest Registry (4) and cases in which no citizen responder was within the radius for activation. All cases were validated from pre-hospital medical records and we excluded OHCAs with obvious signs of death; trauma, drowning, or suicide; EMS-witnessed arrests; and OHCAs with a do-not-resuscitate order or without indication for continuing resuscitation by EMS. Cases in which EMS response time was missing and cases without any corresponding survey response were also excluded.

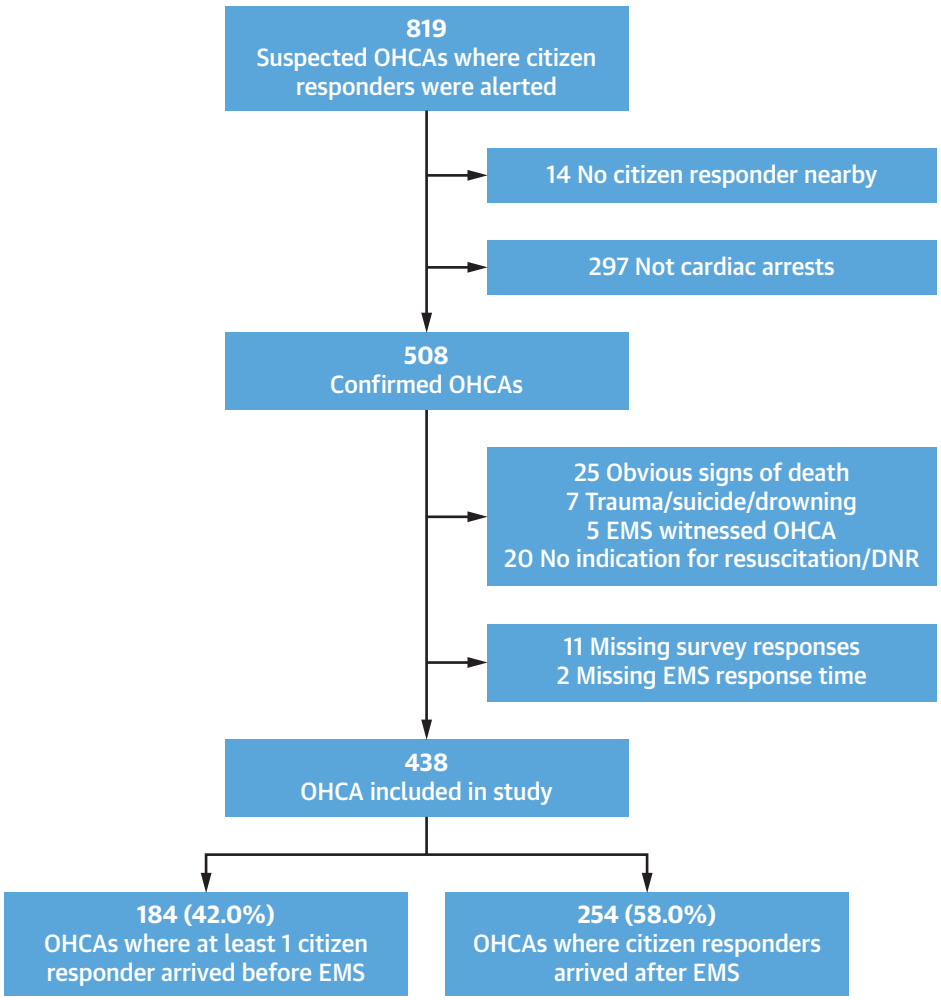
DATA SOURCES. The Danish Cardiac Arrest Registry provided age, sex, and cardiac arrest information according to Utstein criteria (18): first recorded rhythm (defined as shockable if pulseless ventricular tachycardia/ventricular fibrillation was recorded as first rhythm by the EMS, or if the patient was defibrillated by an AED before EMS arrival), witnessed status, location of arrest, EMS response time (defined as time from dispatch of EMS to vehicle stop at scene, not at patient side), bystander CPR, bystander defibrillation, and return of spontaneous circulation. Bystander CPR and bystander defibrillation were reported for all bystander interventions and could therefore also include random bystanders, not only citizen responders. Thirty-day survival was obtained from the Danish Civil Registration System (19).

Information about citizen responders (sex, age, profession, CPR training, registration time) and dispatch information from alarms (timestamps, locations, interactions with alarms) was available from the app server. Citizen responders who responded to the alarm (either accepted, declined, or rejected) were reported as "responded." Those who accepted the alarm or accepted the alarm and then declined after more than 5 min were reported as "accepted." In contrast, those who accepted the alarm and then declined within 5 min were reported as "rejected." Citizen responders who declined the alarm from the start were reported as "declined." Distance from citizen responder to AED and OHCA location was calculated as straight-line distance using the last updated coordinates at the time of selection for alarm. The citizen responder survey was used to identify cases in which citizen responders arrived before EMS, performed CPR, applied an AED, and performed defibrillation.

STUDY OUTCOMES. The primary outcomes of this study were bystander CPR and bystander defibrillation. Physical injuries and degree of psychological impact were selected as safety outcomes.

STUDY EXPOSURE. Cases in which at least 1 citizen responder reported arriving at the OHCA location before EMS were classified as "Citizen responders arrived first." These cases were compared with cases in which no citizen responder reported having arrived before EMS, classified as "EMS arrived first." In both groups, random bystanders could potentially be present and provide CPR and defibrillation before the citizen responders and EMS. Therefore, bystander CPR and bystander defibrillation included involvement from both random bystanders and citizen responders. To evaluate involvement from only citizen responders, the survey was used. In the event of disagreement between survey responses and information from the Danish Cardiac Arrest Registry, the registry was considered as being correct.

FIGURE 1 Selection of OHCA Patients in Study Population

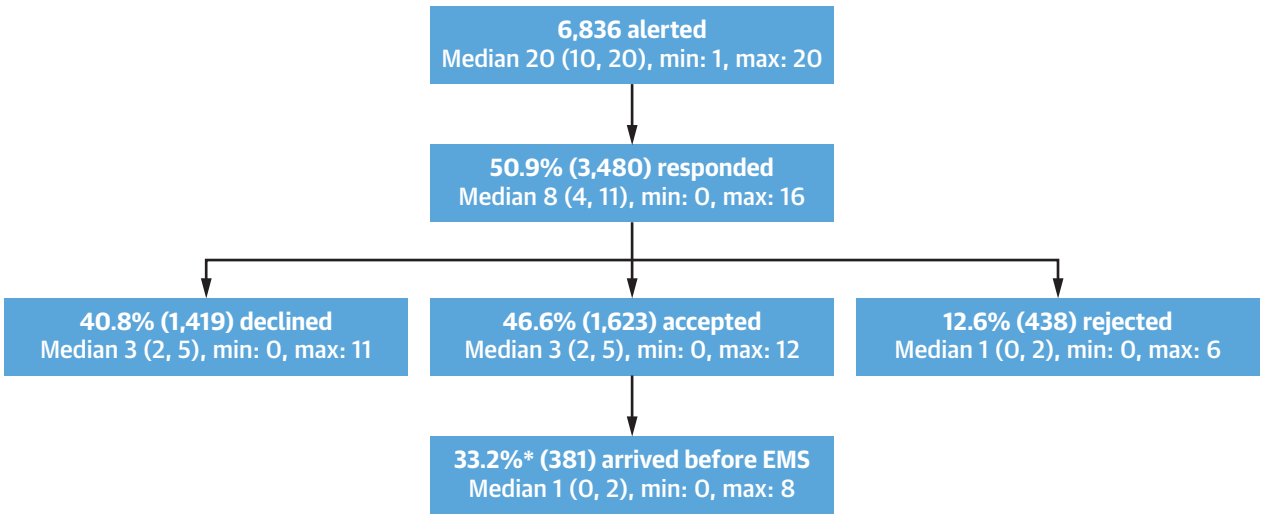


Flowchart illustrating inclusion and exclusion criteria and number of patients in each group. DNR = do not resuscitate; EMS = emergency medical services; OHCA = out-of-hospital cardiac arrest.

STATISTICAL ANALYSIS. Categorical variables were presented as proportions and percentages and analyzed with chi-square test or Fisher exact test when appropriate. Continuous variables were presented as medians with interquartile boundaries because of skew distribution of data and analyzed with Kruskal-Wallis test. Logistic regression analyses were used to examine the association between citizen responders arriving before EMS and bystander CPR and bystander defibrillation. The results are presented as unadjusted odds ratios with 95% confidence intervals. Descriptive analysis was performed overall and stratified by EMS response time in 3 groups: <5 min, 5 to 10 min, and >10 min. Level of statistical significance was defined as 2-sided p value <0.05. Statistical analyses were done in SAS Enterprise Guide version 7.1 (SAS Institute Inc., Cary, North Carolina) and figures were made in R version 3.6.0 and RStudio, Inc., Version 1.0.153, 2009-2017 (20).

ETHICAL APPROVAL. This study was an observational pilot study for the randomized controlled trial, The HeartRunner Trial (NCT03835403). The HeartRunner Trial was assessed by the local ethics committee and accepted without the need for further approval (Journal nr.: 17018804). Patient data collection was approved by the Data Protection Agency (Journal nr.: 2012-58-0004, VD-2018-28, I-Suite nr.: 6222), and the study was registered with the Danish Patient Safety Authority (3-3013-2721/1).

FIGURE 2 Citizen Responder Interaction With the Alarms



Flow chart illustrating number of activated citizen responders in all included out-of-hospital cardiac arrests (n = 438). Number of citizen responders per alarm is reported as median (interquartile boundaries [Q_1, Q_3]) and minimum (min) and maximum (max). accepted = citizen responders who accepted the alarm, including those who accepted and then declined after more than 5 min; alerted = citizen responders alerted by sending an alarm; declined = citizen responders who declined the alarm; EMS = emergency medical services; rejected = citizen responders who first accepted the alarm but then declined the alarm within 5 min; responded = citizen responders who accepted, rejected, or declined the alarm. *Of all citizen responders who accepted the alarm and answered the question regarding arrival before the emergency medical services (n = 1,149).

Citizen responders signed the terms of agreement at registration. They gave their consent to be contacted by the research team and agreed to share their information and location. They could delete the app and withdraw from the citizen responder system at any time. They agreed not to disclose any information about the resuscitation attempt and the patient.

RESULTS

DISPATCH OF CITIZEN RESPONDERS. The citizen responder system was activated in 819 cases of suspected OHCA. Of these, 438 were confirmed cardiac arrests eligible for further analyses. In 42.0% (n = 184), at least 1 citizen responder arrived before EMS (**Figure 1**). Characteristics of OHCAs in which the emergency dispatch center did not activate the citizen responders are reported in Supplemental Table 1.

In the 438 included cases, 6,836 citizen responders were alerted (median 20 [Q_1, Q_3; 10, 20] responders per alarm). A total of 50.9% (n = 3,480) responded to the alarm and 46.6% (n = 1,623) of those accepted the alarm (median 3 [Q_1, Q_3; 2, 5] per alarm) (**Figure 2**). In 8.0% (n = 35) of the cases in which citizen responders were alerted, no citizen responder accepted the alarm. Of all citizen responders who accepted the alarm, a median of 2 citizen responders (Q_1, Q_3; 1, 2) per alarm were sent directly to the OHCA location to perform CPR, and 2 (Q_1, Q_3; 1, 3) were dispatched to retrieve an AED. All citizen responders for whom the app confirmed the alarm received the survey, and 75.3% (n = 2,746) replied. Importantly, 86.3% (n = 1,401) of all citizen responders who accepted the alarm answered the survey. Of those citizen responders, 82.0% (n = 1,149) reported having arrived at the OHCA location and 33.2% (n = 381) arrived before EMS (**Figure 2**).

CARDIAC ARREST CHARACTERISTICS AND OUTCOMES. In the 184 cases in which citizen responders arrived before EMS, 79.9% (147 of 184) occurred in residential locations and EMS response time was longer (median 07:08 min:s compared with 05:05 min:s, $p < 0.001$) (**Table 1**). The percentage of bystander CPR was significantly higher when citizen responders arrived before EMS, 85.3% (157 of 184) compared with 76.8% (195 of 254), $p = 0.027$, and a 3-fold increase in percentage of bystander defibrillation was observed, 21.2% (39 of 184) compared with 6.7% (17 of 254), $p < 0.001$ (**Central Illustration**). An increase in the percentage of 30-day survival was found when citizen responders arrived before EMS, although not statistically significant, 16.1% (29 of 184) versus 13.1% (32 of 254), $p = 0.38$ (**Table 1**).

TABLE 1 Cardiac Arrest Characteristics for OHCAs in Which Citizen Responders Arrived at the OHCA Before EMS (Citizen Responders Arrived First) and OHCAs in Which EMS Arrived Before the Citizen Responders (EMS Arrived First)

	Citizen Responders Arrived First (n = 184)	EMS Arrived First (n = 254)	Missing
Age, yrs	71 (64, 81)	72 (61, 80)	11
Male	125 (69.1)	167 (67.9)	11
Residential OHCA location	147 (79.9)	209 (82.3)	–
Witnessed arrest	97 (52.7)	144 (56.9)	1
Shockable rhythm (VF/pVT)	61 (33.9)	68 (27.0)	6
Time from call to EMS dispatch, min:s	00:47 (00:33, 01:06)	00:45 (00:33, 01:07)	–
Time from EMS dispatch to EMS vehicle stop, min:s	07:08 (05:27, 09:45)	05:05 (04:00, 06:33)	–
Time difference between EMS dispatch and citizen responder dispatch, min:s	00:23 (00:00, 01:13)	00:51 (00:15, 01:59)	–
Distance between citizen responder and OHCA, m	543 (301, 820)	528 (313, 797)	–
Distance between citizen responder, AED, and OHCA, m	754 (484, 1144)	740 (492, 1063)	–
EMS defibrillation	50 (27.2)	84 (33.1)	
ROSC on hospital arrival	57 (31.0)	77 (30.4)	1
30-day survival	29 (16.1)	32 (13.1)	14

Values are median (Q_1, Q_3), n (%), or n.

AED = automated external defibrillator; CPR = cardiopulmonary resuscitation; EMS = emergency medical services; OHCA = out-of-hospital cardiac arrest; Q_1, Q_3 = interquartile boundaries; ROSC = return of spontaneous circulation; pVT = pulseless ventricular tachycardia; VF = ventricular fibrillation.

According to survey responses, citizen responders performed CPR in 68.5% (126 of 184), applied an AED in 49.5% (91 of 184), and performed defibrillation in 10.3% (19 of 184) of the OHCAs in which they arrived before EMS (Figure 3).

OUTCOMES ACCORDING TO EMS RESPONSE TIME. When stratifying OHCAs according to EMS response time, citizen responders were more likely to arrive before EMS with increasing response time: 23.3% (35 of 150), 46.7% (107 of 229), and 71.2% (42 of 59) for EMS response time <5 min, 5 to 10 min, and >10 min, respectively. A statistically significant higher percentage of bystander CPR was observed only in the 5 to 10 min group when citizen responders arrived first (87.9% vs. 77.9%, p = 0.047), whereas a higher and increasing percentage of bystander defibrillation was observed for the groups with the longest response time, 5 to 10 min group (21.5% vs. 10.7%, p = 0.026) and >10 min group (31.0% vs. 0%, p = 0.012) (Table 2). We found no statistically significant difference in 30-day survival with increasing EMS response time: 11.8% versus 14.5%, p = 0.78 for the <5 min group, 16.2% versus 12.8%, p = 0.48 for the 5 to 10 min group, and 19.5% versus 5.9%, p = 0.26 for the >10 min group (Table 2).

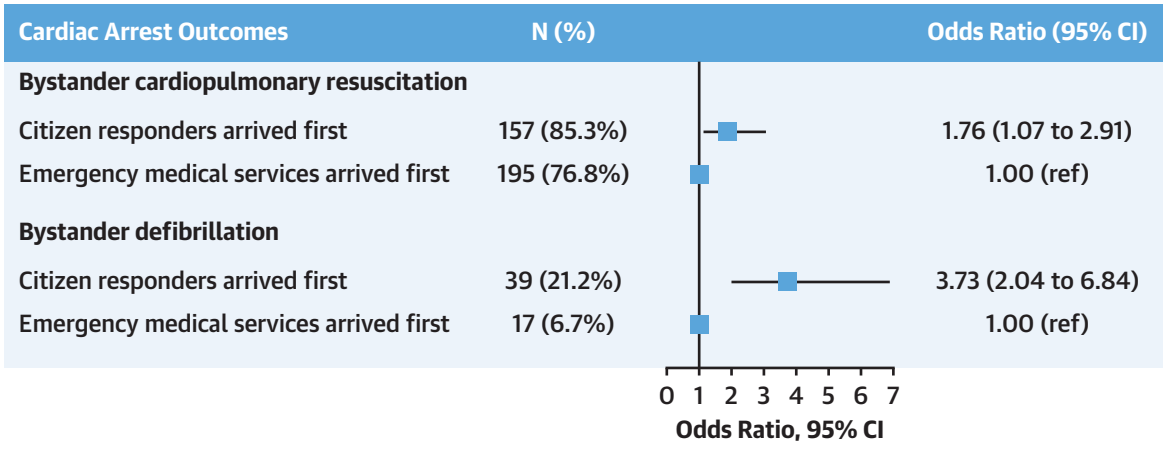
When only including citizen responder interventions and thus excluding random bystanders, we observed an increase in percentage of citizen responder CPR, AED attached, and defibrillation performed with increasing EMS response time among OHCAs in which citizen responders arrived before EMS (Figure 3).

PHYSICAL AND PSYCHOLOGICAL IMPACT FOR CITIZEN RESPONDERS. One of 1,630 citizen responders who completed the question regarding physical injury reported an injury requiring hospital treatment (a lower extremity fracture when running to the OHCA location). Three reported minor injuries without need of treatment, and 2 others reported having been at risk of physical injury on their way to the OHCA location. One reported being at risk of injury or injured but without further details. Among citizen responders who completed the question regarding psychological impact, 1.4% (22 of 1,621) reported their impact as severely affected and 3 of them had a need for professional follow-up. Most activated citizen responders, 99.0% (1,602 of 1,618), wished to continue their enrollment as citizen responders after being dispatched.

DISCUSSION

This prospective observational study advances knowledge regarding implementation of app-dispatched citizen responders to start CPR and defibrillation. We found that citizen responders arrived before EMS in 42% of all OHCAs. A higher percentage of bystander CPR and a 3-fold higher percentage of bystander defibrillation were observed when citizen responders arrived before EMS. Furthermore, the proportion of citizen responders who arrived before EMS and performed CPR and/or defibrillation increased with increasing EMS response time. Last, only a very small percentage of citizen responders experienced severe psychological impact or physical

CENTRAL ILLUSTRATION **Associations Between Citizen Responders Arriving Before Emergency Medical Services and Bystander Cardiopulmonary Resuscitation and Bystander Defibrillation**



Andelius, L. et al. J Am Coll Cardiol. 2020;76(1):43–53.

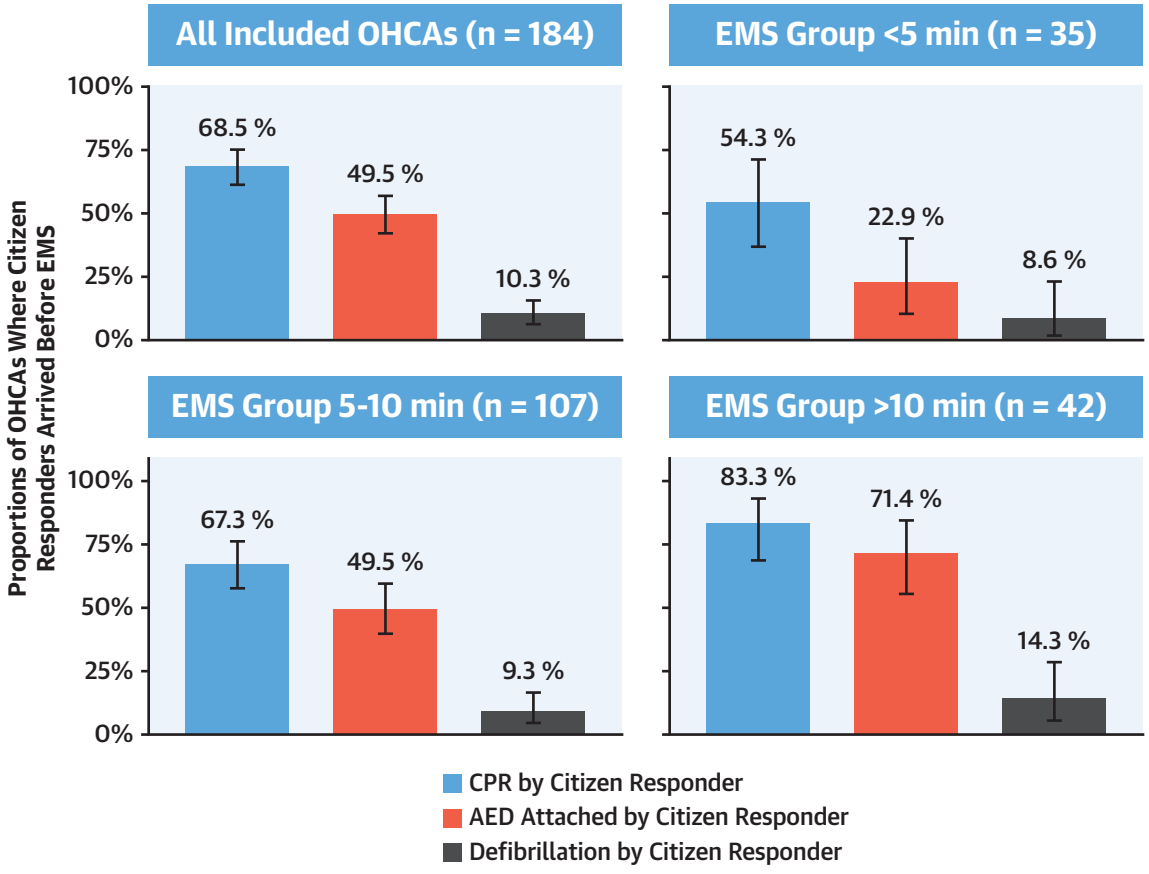
Forest plot reporting odds ratios for the association of citizen responders arriving at the out-of-hospital cardiac arrest location before emergency medical services and bystander interventions (cardiopulmonary resuscitation and defibrillation). Bystander interventions included both citizen responder and random bystander interventions. CI = confidence interval.

injury. Our findings show that dispatching citizen responders through a smartphone app is associated with increased bystander CPR and defibrillation and is safe for the citizen responder.

Although smartphone apps to activate volunteer citizens are currently being implemented in many countries to increase bystander CPR and defibrillation and to improve survival after OHCA, data from such systems remain scarce (11–13). This is the first study to describe the complete chain from activation of citizen responders to arrival at OHCA location and the association with bystander interventions, including the relation to EMS response time. This is important as it provides the opportunity to accurately evaluate citizen responder systems as a supplement to EMS. In the Netherlands, Zijlstra et al. (14) found a reduced time to defibrillation when dispatching citizen responders by text messages (text message responders) compared with EMS. The text message responders performed 7.3% of all early defibrillations within the first 6 min (14). In our study, we had no valid timestamp for when the citizen responder arrived at the scene; therefore, it was not possible to calculate how many minutes before EMS arrival the citizen responders performed CPR or defibrillation. However, overall percentage of bystander defibrillation was 21.2% when citizen responders arrived before EMS compared with 6.7% when EMS arrived first. This can be compared with bystander defibrillation percentage from the Danish Cardiac Registry, including all 5 regions in Denmark, of 6.4% in 2017 and 9.3% in 2018 (4). In this study, citizen responders performed defibrillation in 10.3% of cases in which they arrived before EMS, which might have influenced the observed increase in overall bystander defibrillation percentage. Bystander CPR percentage also increased to 85.3% when citizen responders arrived first compared with 76.8% when EMS arrived first. In 2018, bystander CPR for all regions in Denmark was 77.5% (4). This is higher compared with other countries in Europe and North America (21,22). A randomized trial from Sweden found that bystander CPR could be increased from 48% to 62% by dispatching citizen responders through text messages (10). This indicates that citizen responder systems can be beneficial even in countries with existing high percentage of bystander CPR, and regions with lower percentage of bystander CPR might benefit even more with a citizen responder system leading to increased awareness and an incentive to complete a CPR course.

The present study indicates that when citizen responders reach a patients with cardiac arrest before EMS, the impact on outcome is higher with increasing EMS response times. This suggests that citizen responders have greater potential in areas with longer EMS response times, which also seems to be the case

FIGURE 3 Bystander Interventions Performed by Citizen Responders When They Arrived Before EMS



This figure illustrates the proportion of out-of-hospital cardiac arrests (OHCAs) where citizen responders performed cardiopulmonary resuscitation (CPR), attached an automated external defibrillator (AED), and performed defibrillation when they arrived before emergency medical services (EMS). In the **top left corner**, all included OHCAs are shown. In the **top right corner and lower right and left corners**, OHCAs are stratified by EMS response time.

for professional first responders, such as police and fire fighters (23). Nevertheless, rural areas often have fewer publicly accessible AEDs and fewer inhabitants who can register as citizen responders, which can lead to longer distances and influence the effect of a citizen responder system in these settings. Our setting included both urban and rural areas but with a short median EMS response time of 5 min when EMS arrived first, which might not have left the citizen responders enough time to fetch an AED and arrive before EMS.

We found that the percentage of bystander defibrillation more than tripled when citizen responders arrived before EMS and we found an increase in the percentage of 30-day survival, although not statistically significant (16.1% vs. 13.1%, p = 0.38). However, this study reported 1-year observational data after implementation of a citizen responder system and was not powered to find such a difference. In the Swedish randomized trial of dispatching citizen responders, they found an increase in bystander CPR, but no significant increase in 30-day survival (11.2% vs. 8.6%, p = 0.28) (10). An observational study by Pijls et al. (24) found a 2.8-fold higher chance of survival at hospital discharge for OHCA patients when citizen responders responded to a text-message alert compared with patients in whom the citizen responders did not respond to the alert. In Germany, Stroop et al. (25) found a shorter response time for citizen responders compared with EMS (4 min vs. 7 min) and a higher rate of survival at hospital discharge (18% vs. 7%) if citizen responders started CPR compared with patients in whom EMS started CPR, but they found no statistically significant difference in survival when comparing with patients in whom random bystanders started CPR (25). This emphasizes the importance of reporting bystander interventions by both citizen responder and random bystanders, because citizen responders can arrive

TABLE 2 Cardiac Arrest Characteristics for OHCAs in Which Citizen Responders Arrived at the OHCA Before EMS (Citizen Responders Arrived First) and OHCAs in Which EMS Arrived Before the Citizen Responders (EMS Arrived First) Stratified Into 3 Groups by EMS Response Time

	EMS Response Times								
	<5 Min Group (n = 150)			5–10 Min Group (n = 229)			>10 Min Group (n = 59)		
	Citizen Responders Arrived First	EMS Arrived First	Missing	Citizen Responders Arrived First	EMS Arrived First	Missing	Citizen Responders Arrived First	EMS Arrived First	Missing
Cardiac arrests	35	115		107	122		42	17	
Age, yrs	70 (64, 78)	71 (61, 80)	5	71 (65, 82)	71 (62, 81)	5	74 (65, 79)	74 (58, 82)	1
Male	25 (73.5)	76 (68.5)	5	74 (69.8)	78 (66.1)	5	26 (63.4)	13 (76.5)	1
Residential location	23 (65.7)	91 (79.1)	–	88 (82.2)	102 (83.6)	–	36 (85.7)	16 (94.1)	–
Witnessed	20 (57.1)	59 (51.3)	–	55 (51.4)	72 (59.5)	1	22 (52.4)	13 (76.5)	–
Shockable rhythm (VF/pVT)	7 (20.6)	30 (26.3)	2	38 (36.5)	34 (28.1)	4	16 (38.1)	4 (23.5)	–
Time from call to EMS dispatch, min:s	00:46 (00:31, 01:03)	00:46 (00:35, 01:09)	–	00:46 (00:33, 01:00)	00:44 (00:33, 01:05)	–	00:57 (00:38, 01:15)	00:41 (00:25, 00:57)	–
Time from EMS dispatch to EMS vehicle stop, min:s	04:10 (03:23, 04:33)	03:53 (02:59, 04:26)	–	07:05 (06:13, 08:22)	06:06 (05:18, 07:16)	–	11:30 (10:40, 13:55)	13:38 (11:12, 14:18)	–
Time difference between EMS dispatch and citizen responder dispatch, min:s	00:07 (00:00, 00:37)	00:39 (00:12, 01:22)	–	00:21 (00:00, 01:12)	00:59 (00:21, 02:13)	–	00:47 (00:10, 01:55)	01:38 (00:55, 04:18)	–
Distance between citizen responder and OHCA, m	422 (225, 717)	475 (267, 702)	–	534 (304, 813)	578 (360, 883)	–	694 (429, 954)	616 (333, 868)	–
Distance between citizen responder, AED and OHCA, m	566 (368, 862)	661 (453, 990)	–	765 (497, 1,150)	805 (539, 1,139)	–	901 (617, 1,329)	715 (517, 1,121)	–
EMS defibrillation	9 (25.7)	36 (31.3)	–	30 (28.0)	42 (34.4)	–	11 (26.2)	6 (35.3)	–
Bystander CPR	27 (77.1)	84 (73.0)	–	94 (87.9)	95 (77.9)	–	36 (85.7)	16 (94.1)	–
Bystander defibrillation	3 (8.6)	4 (3.5)	–	23 (21.5)	13 (10.7)	–	13 (31.0)	0 (0)	–
ROSC on hospital arrival	11 (31.4)	35 (30.4)	–	36 (33.6)	36 (29.8)	1	10 (23.8)	6 (35.3)	–
30-day survival	4 (11.8)	16 (14.5)	6	17 (16.2)	15 (12.8)	7	8 (19.5)	1 (5.9)	1

Values are n, median (Q_1, Q_3), or n (%). Distances are straight-line distance.
Abbreviations as in Table 1.

before EMS but might not perform CPR and/or defibrillation if a random bystander is already present performing CPR and/or defibrillation.

PHYSICAL AND PSYCHOLOGICAL IMPACT FOR THE CITIZEN RESPONDERS. The citizen responders volunteer to attend OHCA resuscitation and most have previous CPR training. This might render them less vulnerable to psychological distress compared with random bystanders when experiencing an OHCA. In our study, fewer than 2% were severely affected when reporting psychological impact. This proportion was lower compared with a study by Zijlstra et al. (26) in which 13% experienced short-term severe psychological impact, but none experienced long-term severe distress assessed in text message responders. Although we did not investigate long-term stress in this study, our results indicate that citizen responders are a resilient population and that citizen responder programs appear safe to implement in our setting. Nevertheless, debriefing programs should be available to offer support to those in need (26,27).

STUDY LIMITATIONS. This study is limited by its observational nature, and the results should be interpreted as associations and not as causalities. We categorized OHCAs into 2 groups based on survey responses. Thus, cases classified as "EMS arrived first" were those for which no citizen responder reported having arrived before EMS. Because we did not have a complete survey response rate, it is possible that a case was misclassified as "EMS arrived first" if a citizen responder arrived before EMS but did not complete the survey. Furthermore, the survey was self-reported and not validated, which is why misclassification of CPR, AED attached, and defibrillation by citizen responders could occur.

Our findings are based on observational data of the first year following the implementation of a citizen responder system. To fully understand the effect of citizen responder systems, it is essential to conduct randomized studies investigating survival after OHCA, taking into consideration the potential negative impact for citizen responders. A randomized controlled trial has been initiated in the Capital Region of Denmark (The HeartRunner Trial; NCT03835403).

CONCLUSIONS

During the first year following the implementation of a smartphone app-based citizen responder system, citizen responders arrived before EMS in 42.0% of all OHCAs. Arrival of citizen responders before EMS was

associated with an increase in odds for bystander CPR and the odds for bystander defibrillation more than tripled. Further studies including randomized trials are necessary to determine the effect of dispatched citizen responders on survival after OHCA.

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PERSPECTIVES

COMPETENCY IN SYSTEMS-BASED PRACTICE: Smartphone activation of citizen responders increases initiation of cardiopulmonary resuscitation and defibrillation when these responders reach the scene of OHCA before EMS, particularly when EMS response is delayed.

TRANSLATIONAL OUTLOOK: Randomized trials are necessary to quantify the impact of citizen responder systems on survival after OHCA including potential risk for physical injuries and psychological distress for the citizen responders.

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KEY WORDS AED, cardiopulmonary resuscitation, citizen responder, OHCA, smartphone app, volunteer

APPENDIX For supplemental information and a table, please see the online version of this paper.