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FASTTRACK CLINICAL RESEARCH
Epidemiology and prevention

Alert system-supported lay defibrillation and basic life-support for cardiac arrest at home

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Aims

Automated external defibrillators (AEDs) are placed in public, but the majority of out-of-hospital cardiac arrests (OHCA) occur at home.

Methods and results

In residential areas, 785 AEDs were placed and 5735 volunteer responders were recruited. For suspected OHCA, dispatchers activated nearby volunteer responders with text messages, directing two-thirds to an AED first and one-third directly to the patient. We analysed survival (primary outcome) and neurologically favourable survival to discharge, time to first defibrillation shock, and cardiopulmonary resuscitation (CPR) before Emergency Medical Service (EMS) arrival of patients in residences found with ventricular fibrillation (VF), before and after introduction of this text-message alert system. Survival from OHCAs in residences increased from 26% to 39% {adjusted relative risk (RR) 1.5 [95% confidence interval (CI): 1.03–2.0]}. RR for neurologically favourable survival was 1.4 (95% CI: 0.99–2.0). No CPR before ambulance arrival decreased from 22% to 9% (RR: 0.5, 95% CI: 0.3–0.7). Text-message-responders with AED administered shocks to 16% of all patients in VF in residences, while defibrillation by EMS decreased from 73% to 39% in residences ($P < 0.001$). Defibrillation by first responders in residences increased from 22 to 40% ($P < 0.001$). Use of public AEDs in residences remained unchanged (6% and 5%) ($P = 0.81$). Time from emergency call to defibrillation decreased from median 11.7 to 9.3 min; mean difference –2.6 (95% CI: –3.5 to –1.6).

Conclusion

Introducing volunteer responders directed to AEDs, dispatched by text-message was associated with significantly reduced time to first defibrillation, increased bystander CPR and increased overall survival for OHCA patients in residences found with VF.

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Key Question

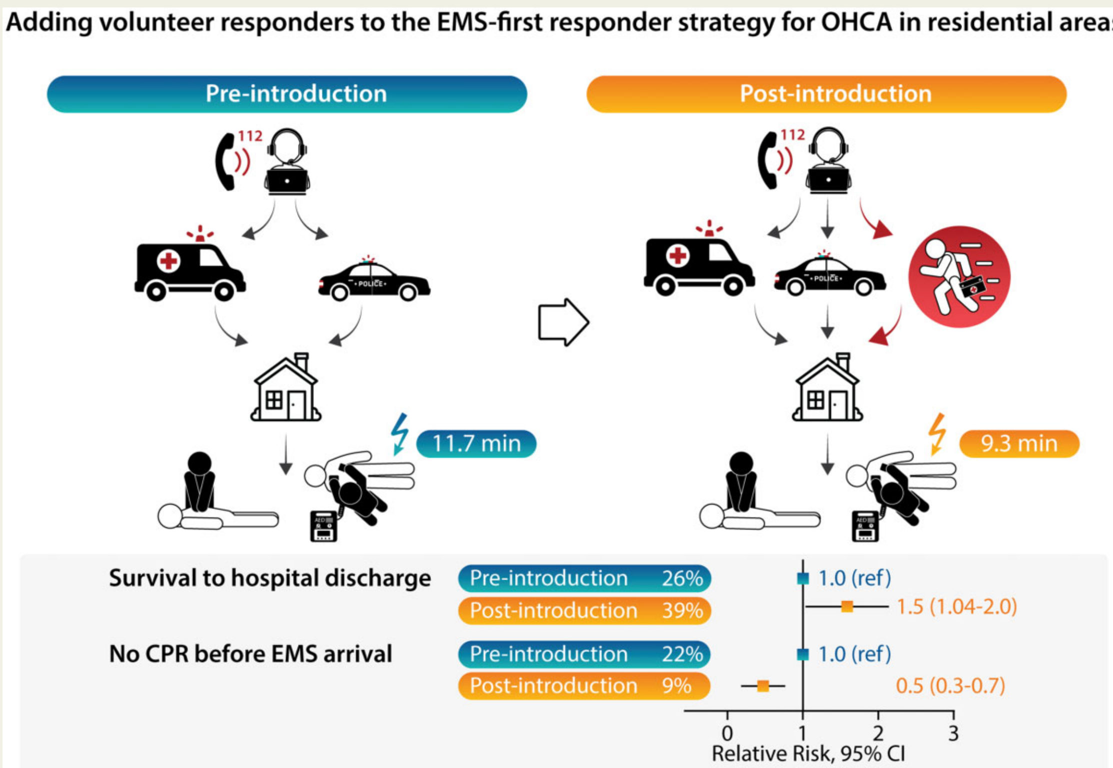
The Emergency Medical Service introduced a text-message alert system to alert volunteers close to an out-of-hospital cardiac arrest patient. In addition, 785 automated external defibrillators (AEDs) were added and made available in the community. Does adding this system result in more basic life support (BLS), earlier defibrillation, and better survival?

Key Finding

We found that BLS increased from 78% to 91%, the time from emergency call to the first defibrillation shock decreased by 2.6 min and survival for patients at home, and found in ventricular fibrillation, increased from 26% to 39%.

Take Home Message

For patients with a cardiac arrest at home, an alert system that includes nearby volunteers activated by the ambulance dispatch centre and many easily accessible AEDs really saves lives. Implementation is an effective community effort.



Structured Graphical Abstract A summary of the key design features and outcomes of introduction of volunteer responders to the EMS response for OHCA in residences. In the left panel (pre-introduction, blue) only EMS and first responders were dispatched to the residence of the suspected OHCA. In the right panel (post-introduction, orange) nearby volunteer responders (red) with access to nearby AEDs were alerted with a text-message in addition to the conventional responders. The time interval between 112 call and the first delivered defibrillation shock is indicated with the patient, survival and absence of CPR before EMS arrival is shown in the lower part, both as percentage and as Relative Risk with the associated 95% CI. CI, Confidence Interval; CPR, cardio-pulmonary resuscitation; EMS, Emergency Medical Services; OHCA, Out-of-hospital cardiac arrest; ref, reference group.

Keywords Automated external defibrillator • Heart arrest • Ventricular fibrillation • Defibrillation • Cardiopulmonary resuscitation • Dispatch • Volunteer responder

Introduction

Automated external defibrillators (AEDs) have been introduced for early defibrillation in out-of-hospital cardiac arrest (OHCA) and proved effective in the public domain.[1–3] Attention therefore has focused mainly on public access defibrillation programmes.[4–9] The prospect of survival from cardiac arrest occurring at home has been worse than for those occurring in public.[10] The most important explanation for this lower survival is fewer witnessed arrest, less bystander cardiopulmonary resuscitation (CPR), and possibly differences in pre-arrest morbidity, all leading to a lower prevalence of a shockable rhythm.[11] Therefore the benefit of AEDs in residences is expected to be less.

Yet, 60–80% of the OHCA occurs at home.[10,12] Despite the lower prevalence of shockable rhythms, patients who collapse from a shockable rhythm at home outnumber those in public.[13,14] Public AEDs serve only few residential patients: in the Public Access Defibrillation trial of 2004, only 15% of the patients were in residences, in the Dutch experience in 2006–09, only 0.6% of patients were in residences, in Seattle 2% in 2011, and in Japan in 2015 only 1.1% of patients in residential locations had an AED connected.[1,13,15,16]

To better assist patients in cardiac arrest at home, in 2006, an automated system was developed that utilizes text-messaging to alert local trained volunteer responders. Emergency Medical Service (EMS) dispatchers activated this text-message alert system (text-message system) to alert volunteer responders with a text message (text-message responders) close to patients with a suspected cardiac arrest and guided them to a nearby AED or directly to the victim. AEDs were moved to the outside of buildings and additional AEDs were placed in residential areas. The purpose of this study was to investigate if this system improved survival of patients with OHCA in residences found in ventricular fibrillation (VF).

Methods

Setting and function of the text-message alert system

The AmsteRdam REsuscitation STudy (ARREST) is an ongoing prospective registry of all OHCA in the province of North Holland. This study included the region North-Holland North (land area 1421 km^2, urban area 128 km^2, total population 615 000 inhabitants). For details, see Supplementary material online, *Tables S4* and *S5*. Routine data collection included information from the dispatch centre, EMS, including the recordings from EMS defibrillators and from treating hospitals up to discharge, described elsewhere.[13]

The text-message system is described earlier.[17] Briefly, a database included the location of AEDs and the home and work address of text-message responders who volunteered to participate in the system. These text-message responders were non-medical persons who had followed a general course in CPR and AED use. Off-duty health care professionals could also participate. When a cardiac arrest was suspected, the dispatcher triggered a computer algorithm that determined the presence of AEDs and the expected presence of text-message responders in a circle around the patient with a progressive diameter up to 1000 m. A text message with the location of the patient and the location of an AED was sent to the private mobile phones of a maximum of 30 responders closest to the patient. Two-thirds of the text-message responders received a text message to collect a local AED first, one-third to go to the patient and start CPR (see Supplementary material online, *Text 1*). By protocol, text messages were not issued for suspected cardiac arrests with a traumatic cause or for children <8 years of age.

Before introduction of the text-message system, local AED owners (who financed the purchase of AEDs) were encouraged to move them to easily accessible boxes outside their buildings. Additional AEDs were placed predominantly in residential areas. At the end of the study period, 785 AEDs (6.1 per km^2 urban area) and 5735 text-message responders (44.7 per km^2 urban area) were registered in the dispatch database.

Independent of our study, the national police introduced AEDs in all patrol cars in the Netherlands in June 2009, coinciding with the first introduction of the text-message system. When an OHCA was suspected by the EMS dispatcher, from that date, police was dispatched to the scene as well.

Study design

We included all patients in North-Holland North of whom dispatchers suspected and EMS confirmed and treated a bystander witnessed or unwitnessed cardiac arrest and with VF. All patients with an OHCA and VF from January 2008 until introduction of the text-message system in 26 municipalities formed the pre-introduction cohort. The dispatch centre introduced the text-message system between July 2009 and March 2013 in a non-randomized stepped-wedge cluster design in these 26 municipalities, after which 100% of the population of the study region was covered by the text-message system (*Figure 1* and Supplementary material online, *Figures S1* and *S2*). The introduction and change-over from control to intervention status was not centrally controlled but determined by logistical factors in each municipality, when sufficient AEDs were installed, and when a sufficient number of local volunteers had been trained. The decision criteria to initiate the text-message system in each municipality are described in Supplementary material online, *Text 2*. All patients with an OHCA and VF from 6 months after the introduction of the text-message system until March 2015 formed the post-introduction cohort.

Data collection and definitions

All surviving patients were asked for informed consent, at least 3 months after the event. Personal identifying data and hospital information of surviving patients who did not give consent were removed from the database and not used in the analysis. From the outcomes, overall survival was included, but neurologic intact survival and hospital treatment was not included. The Institutional Review Board of the Academic Medical Center approved the ARREST data collection, including the use of data from dead patients and limited use of data from survivors who refused consent. From all cardiac arrests, we collected patient- and resuscitation-related data according to standard procedures in the ARREST study and to Utstein recommendations.[18] Study personnel downloaded data from any AED that had been utilized and synchronized the clock time of the AED recording with the network time. Data from all EMS defibrillators involved in OHCA cases in the study were transmitted to the study centre and their clock times were synchronized with the network time as well. Specifically for this study, we recorded if a text-message alert was sent. It was not recorded how many text-message responders had actually responded and what assistance they had given, other than AED use.

Presence of VF as initial recorded rhythm was verified from the downloaded AED or EMS defibrillator recording or from EMS reports. If the AED recording was missing, VF was assumed if an AED shock was reported. A text-message responder was any volunteer who participated in the text-message system under investigation and had no duty to respond. First responders in this study were dispatched police officers equipped with AEDs with a duty to respond. Onsite AEDs were used by not-dispatched bystanders, often witness of the arrest. Residences were private homes or apartment buildings, including nursing homes and old-age homes. Public areas were all other places. Neurologic intact survival was defined as Cerebral Performance Category 1 or 2 (none, or mild/moderate cerebral disability but with independent functioning).[19]

Outcomes and data analysis

The primary outcome of the study was survival to hospital discharge for patients with VF. Secondary outcomes were the proportion of patients receiving CPR before arrival of EMS (irrespective of who delivered CPR),

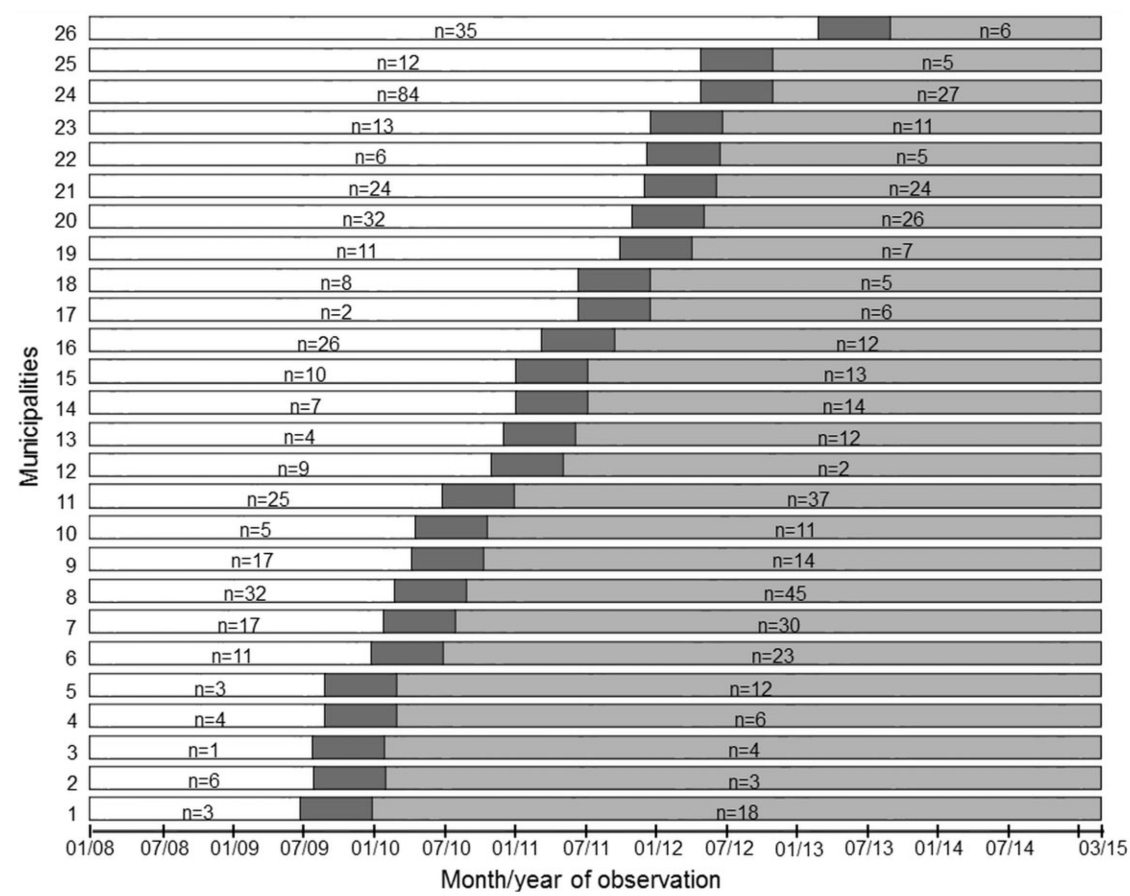


Figure 1 Stepped wedge cluster design. The text-message alert system was introduced stepwise in 26 municipalities between July 2009 and March 2013, followed by a 6-month transition period, indicated by the dark grey bar. The white bar is the pre-introduction period, the light grey bar the post-introduction period used in the analysis. The number in each bar represents the number of cases (ventricular fibrillation, residential and public). The observation period started 1 January 2008 and ended 28 February 2015.

the interval between the call to the dispatch centre and the first defibrillation shock from either ambulance defibrillator or AED, and neurologically favourable survival to hospital discharge. The sample size calculation assumed a simple before–after design and was based on past experience in the study region, assuming that the text-message system would increase survival of patients in residences found in VF from 10% to 18%. This would require 2 × 375 patients. The study was terminated after inclusion of 785 cases with VF.

We included all cases in a stepped-wedge cluster analysis. The unadjusted relative risk (RR) of survival and its 95% confidence interval (CI) was calculated with a generalized linear model using generalized linear mixed models (GLMMs) to account for the clustered observations within municipalities (binomial distribution, linear linkfunction, exchangeable working correlation) with exposure status (text-message system implemented: yes/no) as determinant and survival as outcome variable. We calculated the adjusted RR by including age, witnessed arrest, and introduction status of police AED use as fixed effects and municipality as random effect in the model. Patients in residences and in public areas were analysed separately. Differences between proportions were calculated with a χ^2 statistic. The variable 'CPR before EMS arrival' was expressed as 'No CPR before EMS arrival' to be able to calculate the RR.

Secondary analysis

Since the introduction of dispatched police with AED in the study region was potentially confounding the estimation of the effect of introduction of text-message responders, we performed a secondary analysis, restricting the analysis to the time period in which the police was alerted as a first responder (Supplementary material online, *Figure S3*). The pre-introduction period in this secondary analysis was limited to the period between June 2009 (when the police started using AEDs) until the introduction of the text-message system in each municipality. The post-introduction period was the same as in the main analysis. The same analytical strategy was used as in the main analysis, except that we calculated the adjusted RR without the introduction status of dispatched police AEDs as covariate.

Variance inflation factors were estimated to check on collinearity between the various factors in our models. Factors with a value <5 were considered to indicate no substantial collinearity.

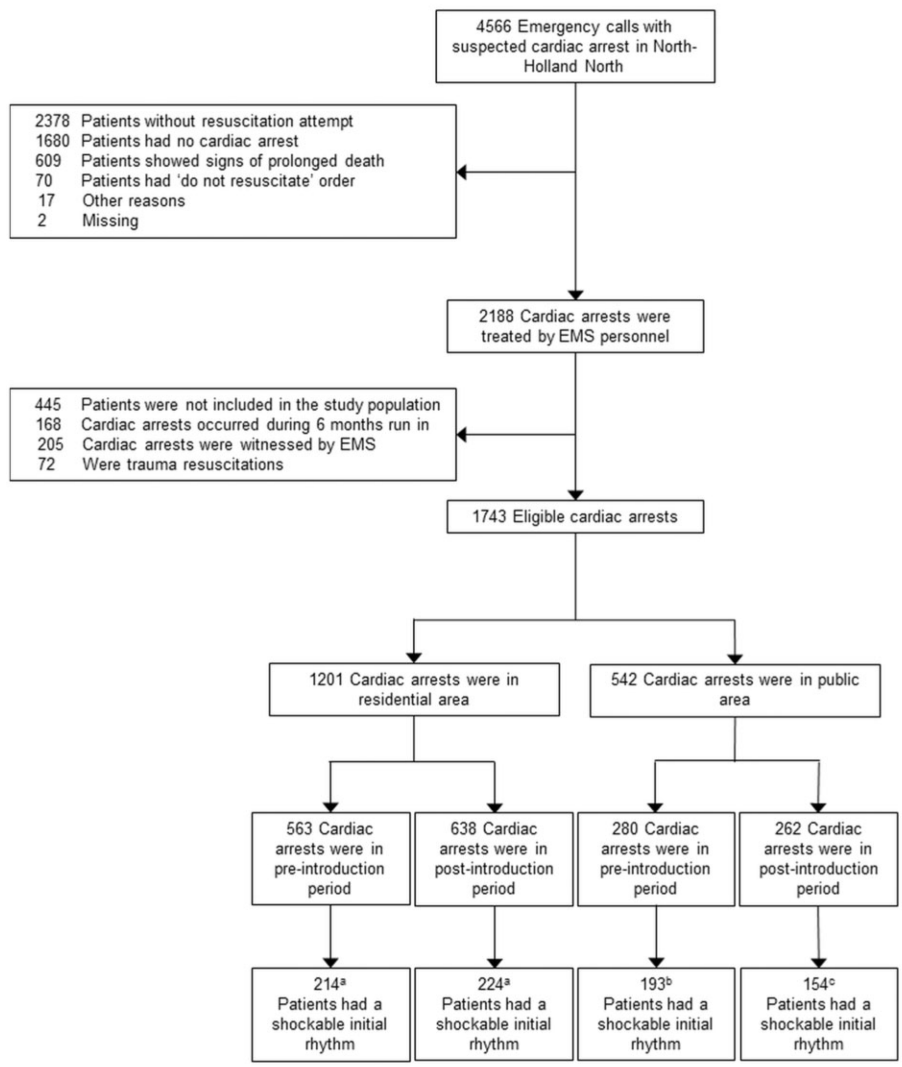


Figure 2 Flow of patients before and after introduction of the text-message alert system, excluding the run-in period. EMS, emergency medical service.

All statistical analyses were performed with IBM SPSS v 26 for Windows.

Results

Figure 2 shows the flow of patients in the study. In residences, the proportion of patients with VF was 38% in the pre-introduction period and 35% in the post-introduction period. In public, these percentages were 69% and 59%, respectively. Baseline characteristics of the pre-introduction and the post-introduction period are shown in *Table 1*. Age, sex, and bystander witnessed arrests did not significantly differ between pre- and post-introduction periods. After introduction of the text-message system, significantly less first shocks were given by EMS. As designed, text-message responders only defibrillated after introduction of the system and delivered 16% and 8% of all shocks in residences and in public, respectively. Onsite AEDs used by bystanders (not alerted by a dispatcher) rarely contributed to defibrillation in residential areas.

Primary endpoint

Among patients who collapsed in a residence and had VF as first recorded rhythm, survival to hospital discharge increased significantly from 55/214 (26%) pre-introduction to 87/224 (39%) post-introduction [adjusted RR 1.5 (95% CI: 1.03–2.0)] (*Table 2*). Survival to hospital discharge of patients found with VF in public did not change significantly: 101/193 (52%) pre-introduction to 79/154 (51%) post-introduction [adjusted RR 0.9 (95% CI; 0.7–1.02)]. The interaction between location and text-message system was statistically significant ($P = 0.014$). Adding sex and time to EMS arrival in the multivariable analysis did not change the RR of survival to discharge.

Outcome data on the total population, including patients with non-shockable initial rhythms are shown in Supplementary material

Table 1 Patient and process characteristics of patients with a shockable initial rhythm in residences or in public

Variables	Residential			Public		
	Pre-introduction cohort	Post-introduction cohort	*P*-values	Pre-introduction cohort	Post-introduction cohort	*P*-values
All patients, *n*	214	224		193	154	
Demographics						
Age, years, mean ± standard deviation	67 ± 12	66 ± 12	0.46	62 ± 14[a]	63 ± 15	0.56
Male sex, *n* (%)	169 (79)	178 (80)	0.90	167 (87)	132 (86)	0.80
Process						
Bystander witnessed arrest, *n* (%)	172 (81)[b]	190 (85)	0.27	166 (87)[c]	135 (88)	0.84
Time to EMS arrival, median (25th–75th percentile), min	8.5 (7.0–11.0)[d]	9.0 (7.0–11.0)[e]	0.83	9.0 (6.0–11.0)[f]	10.0 (7.0–12.0)[f]	0.008
First shock given on VF[g]						
By EMS defibrillator, *n* (%)	154 (73)	87 (39)	<0.001	108 (56)	44 (29)	<0.001
By text-message rescuer AED, *n* (%)	–	36 (16)		–	12 (8)	
By first responder AED, *n* (%)	46 (22)	89 (40)	<0.001	41 (21)	47 (31)	0.035
By onsite AED, *n* (%)	12 (6)	11 (5)	0.81	43 (22)	50 (33)	0.034
Patients admitted to hospital, *n* (%)	108 (51)	128 (57)	0.16	124 (64)	108 (70)	0.19
PCI performed, *n* (% of admitted patients)	48 (45)[c]	56 (45)[h]	0.94	65 (52)	49 (47)[h]	0.42
TTM received, *n* (% of admitted patients)	83 (80)[i]	100 (81)[i]	0.58	64 (53)[h]	63 (60)[h]	0.29

All *P*-values are calculated with generalized linear mixed models, adjusted for clustering in municipalities.
AED, automated external defibrillator; EMS, emergency medical service; PCI, percutaneous coronary intervention; TTM, therapeutic temperature management; VF, ventricular fibrillation.
[a]Data of three patients were missing. Mean value and standard deviation are calculated on the basis of the total number of patients, excluding the one with missing data.
[b]Data of one patient was missing. Percentages were calculated on the basis of the total number of patients, excluding the one with missing data.
[c]Data of two patients were missing. Mean value and standard deviation is calculated on the basis of the total number of patients, excluding the two with missing data.
[d]Data of 22 patients were missing. Median times and percentiles were calculated on the basis of the total number of patients, excluding the 22 with missing data.
[e]Data of 11 patients were missing. Median times and percentiles were calculated on the basis of the total number of patients, excluding the 11 with missing data.
[f]Data of 14 patients were missing. Median times and percentiles were calculated on the basis of the total number of patients, excluding the 14 with missing data.
[g]Five patients had VF but no defibrillation shock was given (residential: pre-introduction = 2, post-introduction = 1; public: pre-introduction = 1, post-introduction = 1). Percentages were calculated on the basis of the total number of patients, excluding those where no defibrillation shock was given.
[h]Data of three patients were missing. Percentages were calculated on the basis of the total number of patients, excluding the three with missing data.
[i]Data of four patients were missing. Percentages were calculated on the basis of the total number of patients, excluding the four with missing data.

online, *Table S1*. While survival rates were much lower, unadjusted and adjusted RR of overall and neurologic intact survival to hospital discharge remained significant in the residential patients after introduction of the text-message system.

Secondary endpoints

In residences, significantly less patients received no CPR before EMS arrival: it decreased from 22% to 9% (RR: 0.5, 95% CI: 0.3–0.7) after introduction of the text-message system. In public areas, receiving no CPR before EMS arrival decreased significantly from 13% to 6% (RR: 0.5, 95% CI: 0.2–0.95) after introduction of the text-message system. Median time to defibrillation in residences significantly decreased by 2.6 min (expected marginal mean difference –2.6, 95% CI: –3.5 to –1.6). Time to defibrillation in public also decreased significantly by 1.6 min (expected marginal mean difference –1.6, 95% CI: –2.7 to –0.5) (*Table 2* and *Figure 3*). Neurologically favourable survival increased from 24 to 36% in residences, but this increase did not reach statistical significance after adjustment [adjusted RR: 1.4 (95% CI: 0.99–2.0)]. Neurologically favourable survival did not change in public areas (50% pre- and post-introduction), adjusted RR 0.8 (95% CI: 0.6–1.1) (*Table 2*).

Secondary analysis

Patient and process characteristics, limited to the period after AED use by police was introduced, are shown in Supplementary material online, *Table S2*. As a consequence of the constraint in observation period, the size of the pre-introduction cohort was about half of that of the primary analysis. The contribution of first responders in defibrillation in residences was 40% both in the pre- and post-introduction period. Primary and secondary outcomes are shown in Supplementary material online, *Table S3*. Survival to hospital discharge in the secondary analysis increased not significantly with an adjusted RR of 1.4 (CI: 0.98–2.0, Supplementary material online, *Table S3*), but the point estimate was almost the same as in the primary analysis.

Variance inflation factors for exposure status, witnessed arrest, police AED use, and patient age were 1.85, 1.14, 1.70, and 1.13, respectively, indicating no substantial collinearity.

Discussion

Our study shows that for patients with OHCA with VF who collapsed in residences, introduction of a text-message system was

Table 2 Primary and secondary outcomes patients with a shockable initial rhythm in residences or in public

Variables	Residential				Public			
	Pre-introduction cohort	Post-introduction cohort	Unadjusted RR (95% CI)	Adjusted RR (95% CI)	Pre-introduction cohort	Post-introduction cohort	Unadjusted RR (95% CI)	Adjusted RR (95% CI)
All patients, *n*	214	224			193	154		
Primary outcome								
Survival to hospital discharge, *n* (%)	55 (26)	87 (39)	1.4 (1.1–1.8)	1.5 (1.03–2.0)	101 (52)	79 (51)	1.0 (0.8–1.23)	0.9 (0.7–1.02)
Secondary outcomes								
Neurologically favourable survival, *n* (%)	51 (24)	77 (36)[a]	1.4 (1.1–1.8)	1.4 (0.99–2.0)	96 (50)[b]	74 (50)[c]	1.0 (0.8–1.3)	0.8 (0.6–1.1)[d]
No CPR before EMS arrival, *n* (%)	46 (22)[e]	21 (9)	0.5 (0.3–0.7)		25 (13)	9 (6)	0.5 (0.2–0.95)	
			MD (95% CI)				MD (95% CI)	
Time to first shock by any defibrillator, min, median (25–75 percentile)	11.7 (8.6–14.5)[f]	9.3 (7.6–11.4)[g]	–2.6 (–3.5 to –1.6)		9.2 (6.4–12.9)[h]	8.0 (5.1–10.9)[a]	–1.6 (–2.7 to –0.5)	
By EMS defibrillator	12.5 (10.1–15.7)[i]	11.0 (8.7–13.0)[c]	–2.2 (–3.5 to –0.8)		11.4 (8.8–14.3)[j]	11.1 (9.6–14.2)[j]	–0.05 (–1.8 to 1.7)	
By text-message responder AED	–	9.3 (7.7–11.1)	–		–	8.8 (6.2–9.8)[b]	–	
By first responder AED	7.8 (6.0–10.3)[b]	8.4 (7.1–10.2)[c]	0.5 (–0.5 to 1.6)		7.4 (5.3–10.2)[b]	8.5 (6.8–11.0)[b]	1.2 (–0.2 to 2.6)	
By onsite AED	7.4 (1.6–12.9)[k]	5.9 (0.0–9.3)[b]	–1.9 (–5.3 to 1.5)		3.5 (1.6–7.3)[l]	3.9 (1.9–6.4)[e]	–0.3 (–1.8 to 1.2)	

Unadjusted RR: clustering exposure status, Adjusted RR: as unadjusted RR plus adjusted for age, yes/no witnessed collapse and if first responders (police) were equipped with an AED. All analyses were performed on the basis of the total number of patients, excluding the patients with missing data.
AED, automated external defibrillator; CI, confidence interval; EMS, emergency medical system; MD, expected marginal mean difference; RR, relative risk.
[a]Data of nine patients were missing.
[b]Data of one patient was missing.
[c]Data of five patients were missing.
[d]For this model, we used a Poisson distribution to calculate the relative risk, as the model with the binomial distribution to calculate the relative risk did not converge.
[e]Data of two patients were missing.
[f]Data of 14 patients were missing.
[g]Data of 12 patients were missing.
[h]Data of 17 patients were missing.
[i]Data of 8 patients were missing.
[j]Data of four patients were missing.
[k]Data of three patients were missing.
[l]Data of 11 patients were missing.

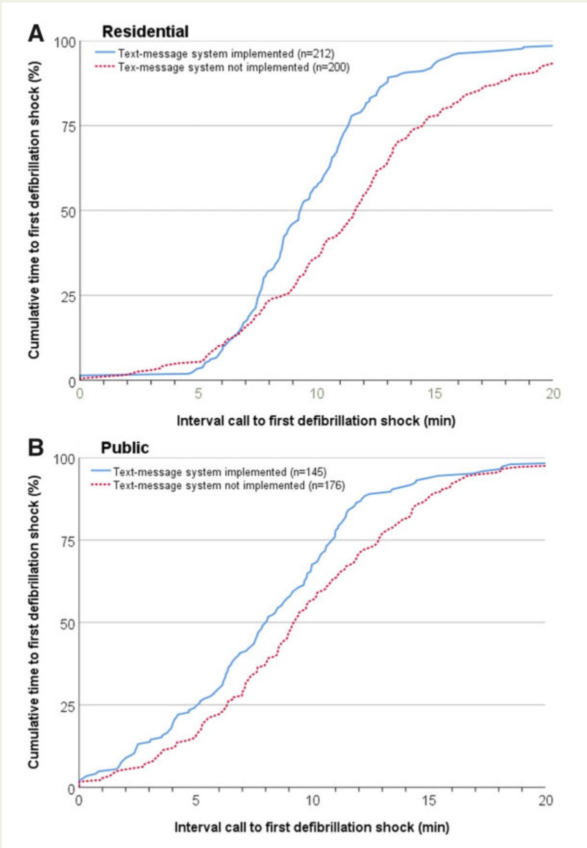


Figure 3 Cumulative time interval between emergency medical service call and the first defibrillation shock. The numbers between brackets in the legend indicate the number of patients of which this time interval was known and contributed to the figure. (*A*) The cumulative time interval for the first defibrillation shock in residencies and (*B*) the first defibrillation shock in public. The cumulative percentage was >0% at 0 min, if an onsite automated external defibrillators provided a defibrillation shock before the dispatch centre was called. Shortening of the time to first shock in residences started to occur after ∼7 min, coinciding with the observed arrival of first responders and text-message responders. In public, the earliest defibrillation of onsite automated external defibrillators already was done before the dispatch centre was alerted.

associated with a higher overall survival, a smaller likelihood that no CPR is given before EMS arrival, and a reduced time to defibrillation. It is reasonable to assume that these process factors—at least partly—explain the increased survival in residences after introduction of the text-message system (*Graphical Abstract*). The finding that the higher survival in residential areas was also demonstrated when all patients, including those with a non-shockable rhythm were analysed, strengthens the importance of introducing such text-messaging systems in the community.

Traditionally, AED programmes focused on public locations where a higher proportion of a shockable initial rhythm can be expected. In contrast, the AED programme investigated in the present study targeted residential areas, where most OHCAs occur. In residences, after introduction of the text-message system, the absolute number of survivors was exceeding and the survival rate was approaching those in public. With the introduction of the text-message system, CPR before EMS arrival increased as well, which probably also contributed to increased survival. It should be noted that in public areas, already a large and increasing number of onsite AEDs was used, delivering a first shock before ambulance arrival in one-fourth to one-third of all cases, while the contribution of AED use from the text-message system was considerably smaller. In residences, the opposite was the case.

In the Netherlands, CPR training programmes for volunteer responders have been successful for many years, explaining the already high proportion of patients receiving CPR before EMS arrival. Also, AEDs for public use were already well accepted. These two factors may explain the high survival rate after OHCA in the Netherlands.[20] The success of a text-message system depends on the availability of sufficient trained volunteers and of sufficient registered AEDs. With the new text-message system in development, municipal authorities were willing to invest in AEDs for residential use and AED owners were willing to place AEDs outside their premises. Placing AEDs outside a building rather than inside made them available at all times, which enhances its usability for the entire community. Without such location outside buildings, accessibility can expected to be severely limited.[21] Previously we have shown that there was a direct relationship between AED density up to two AEDs per km^2 and a text-message responder density of >10 per km^2 for a specific alert and a shorter time to defibrillation and an increased proportion of patients who were defibrillated <6 min after the emergency call.[22] This may be one of the limiting factors in countries where basic life support and/or AED use is less developed and geography and urbanization differ. Developing and investigating the effectivity of such novel strategies is a recommendation in an Institute of Medicine report.[23] Our study provides evidence that an innovative strategy that implemented mobile technology recruiting trained volunteers and AED resources for early defibrillation in the residential community is feasible and effective. However, the purchase and placement of AEDs alone does not ensure that the intended improved response will be achieved. If adopted elsewhere, implementation must be accompanied by efficient dispatching of text-message responders, and the objectives of increased bystander CPR and shortened time to defibrillation should be evaluated.

The AEDs in our project were not placed with an optimization rule based on past cardiac arrests[14,24] or socio-economic status.[8] AED placement was dependent on AEDs made available by local AED owners. Otherwise, placement of municipality-financed AEDs was based on population density or on perceived remote location and expected late EMS arrival. Text-message responders were activated if they were expected to be in the patient's vicinity, based on their known home and work address and the time and day of the week, and not based on their actual location as has been investigated in Stockholm with mobile phone location technology.[25,26] A strategic algorithm in the computerized text-message system directed part of the text-message responders to an AED if they were expected to be close to the device, or otherwise guided the text-message responders directly to the patient to perform CPR in a dual dispatch system. This strategy resulted in the text-message responder being the first to defibrillate in 16% of all cases in residential areas.

After introduction of the text-message system, the time to defibrillation by EMS also decreased and it may appear that this contributed to the observed increase in survival. However, the ambulance response time from call to arrival did not change, and the proportion of instances where EMS defibrillated first, actually decreased from 73% to 39% in residences (*Table 1*). The probability that a late arriving EMS team found the patient already defibrillated by an AED was higher than for an early arriving EMS team. Therefore only the earliest arriving EMS teams defibrillated and their median time to defibrillation then should be expected to be shorter than before introduction of the text-message system. The findings of Andelius *et al*. point in the same direction: the probability that a citizen responder was the first to arrive and defibrillate was the highest when EMS arrived on scene >10 min after the call to the dispatch centre.[27]

The introduction of dispatched police with AEDs as first responders coincided with the introduction of our text-message system, requiring specific control for confounding in the analysis. This was done by adding it as a covariate in the multivariable analysis. In addition, we repeated the analysis, limited to the time period after introduction of the police as first responder (Supplementary material online, *Figure S3* and Supplementary material online, *Tables S2* and *S3*). This showed a point estimate of the contribution of text-message responders that was almost the same as in the main analysis. This suggests that the measured adjusted RR of survival in the main analysis was not confounded by the police first responders.

Previous research questioned the added value of adding another type of first responder to a system with already one or more active first responders. Sayre *et al*. did not find a difference in survival after adding police first responders with AEDs in a first responder system with dispatched fire fighters.[28] Our results indicate that the text-message responders did not compete with the dispatched first responders (such as police and fire fighters), but acted complementary to them, replacing slower EMS arrivals. This suggests that adding a text-message system to a system that already has a first response system can still strengthen the first response system as a whole.

There are opportunities to further enhance the text-message system. A smart-phone location system would better select the closest responders similar to the system described in Stockholm and Copenhagen, and also may guide them faster to the nearest AED and to the patient with a road map on their smart-phone.[26,27] This approach is now adopted in the Netherlands as well. Also, in a number of the potential cases, the dispatcher may not have activated the text-message system, partly because the need for resuscitation was not recognized or because the dispatcher believed that an ambulance was already nearby.[17] Increasing the density of AEDs and responders in the text-message system may further shorten the time to the first defibrillation.[22,29]

Limitations

This study has several limitations. First, the stepwise introduction of the text-message system in municipalities was a pragmatic study design that was acceptable in the community, in contrast to random allocation to municipalities (see Supplementary material online, *Text 2*). It carries the risk of confounding by an underlying temporal survival trend or co-interventions. The GLMM analysis adjusted for cluster effects witnessed arrest and for concomitant police AED introduction, reducing the risk of confounding of known factors. This was also supported by the analysis of collinearity with variance inflation factors. During the years of the study, no changes in hospital treatment protocols were introduced, as is also shown in *Table 1* for percutaneous coronary intervention or therapeutic temperature management.

Second, the non-randomized design limits a causal interpretation of the survival effect in residences, even while significantly higher bystander CPR rates and significantly shorter time to defibrillation are recognized favourable determinants of survival. Other unidentified factors may play a role as well. Third, local factors such as demographic and geographic factors and population willingness to support the programme may be different in other regions and countries.

Fourth, although we could precisely analyse the contribution of text-message responders to (early) defibrillation, we could not analyse their contribution to the increase in CPR that was observed as well. It is likely that text-message responders initiated CPR when this was not already started earlier, but how often it was their contribution or that of the first responders remains uncertain.

As this study was not a randomized study, the study protocol was not pre-registered. The study was, however, performed according to the pre-specified non-randomized stepped-wedge cluster design.

Conclusion

In communities in the Netherlands, implementation of a programme that dispatched volunteer responders by text message to collect AEDs and/or perform CPR was associated with increased bystander CPR rates, with shortened time to defibrillation and with higher survival to hospital discharge for patients in residences experiencing cardiac arrest and VF.

Supplementary material

Supplementary material is available at *European Heart Journal* online.

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