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Global positioning system alerted volunteer first responders arrive before emergency medical services in more than four out of five emergency calls

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1
2 **Global positioning system alerted volunteer first responders**
3 **arrive before emergency medical services in more than four**
4 **out of five emergency calls**
5

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26 cardiopulmonary resuscitation; out-of-hospital cardiac arrest; OHCA, bystander; GPS; survival

27 **Abstract:**

28 Aim:

29 To evaluate response rates for volunteer first responders (VFRs) activated by use of a smartphone GPS-
30 tracking system and to compare response times of VFRs with those of emergency medical services (EMS).
31 Furthermore, to evaluate 30-day-survival after out-of-hospital cardiac arrest (OHCA) on a rural island.

32 Methods:

33 Since 2012 a GPS-tracking system has been used on a rural island to activate VFRs during all emergency
34 calls requesting an EMS. When activated, three VFRs were recruited and given distinct roles, including
35 collection of the nearest automatic external defibrillator (AED). We retrospectively investigated EMS
36 response data from April 2012 to December 2017. These were matched with VFR response times from the
37 GPS-tracking system. The 30-day survival in OHCA patients was also assessed.

38 Results:

39 In 2266 of 2662 emergency calls (85%) at least one VFR arrived to the site before EMS. Median response
40 times for VFRs (n=2662) was 4:46 min:sec (IQR 3:16-6:52) compared with 10:13 min:sec (6:14-13:41) for
41 EMS (p<0.0001). A total of 17 OHCA's took place in public locations and 65 in residential areas. Thirty-day
42 survival in these were 24% and 15%, respectively.

43 Conclusion:

44 Use of a smartphone GPS-tracking system to dispatch VFRs ensures that in more than four of five cases, a
45 VFR arrives to the site before EMS. Response times for VFRs were also found to be lower than EMS
46 response times. Finally, the 30-day survival of OHCA patients in a rural area, based on these results, surpass
47 our expectations.

48

49 **Introduction**

50 Out-of-hospital cardiac arrest (OHCA) is a leading cause of sudden death in industrialized countries (1). In
51 Denmark, public initiatives have increased awareness and early action during cardiac arrest, which may have
52 contributed to the substantial increase in bystander cardiopulmonary resuscitation (CPR) (2, 3). Also, the
53 number of onsite available automated external defibrillators (AEDs) has grown and a national volunteer-
54 based AED-network has been created to increase AED usage (2, 4). Still, survival remains low at about 10%
55 after OHCA (2, 5, 6). In previous studies, bystander defibrillation before the arrival of the emergency
56 medical service (EMS) has shown to increase survival up to 74% (7-9), but these studies were performed in
57 selected high-risk public areas, making it difficult to extrapolate to real-life settings. Further, about three-
58 quarters of OHCA occur in residential areas (6, 10), where CPR performance, defibrillation and survival are
59 markedly lower compared with OHCA in public areas (11). Recently, studies have examined the use of
60 GPS or text-message based systems to alert volunteer first responders (VFRs) (12-14) during suspected
61 cardiac arrest. These studies, however, did not measure the number of on-site VFRs, response-times, nor did
62 they demonstrate prognostic effects of the systems used. In 2012, on the island of Langeland, Denmark, a
63 smartphone application was developed, which used global positioning system (GPS) to locate and dispatch
64 VFRs to emergency sites along with standard EMS response. In each emergency call the selected VFRs were
65 given one of three different tasks.

66 In this study we aim to investigate the response rates and response times for trained VFRs compared to EMS
67 when using a smartphone GPS-tracking system on a rural island. Our secondary aim is to evaluate the 30-day
68 survival after OHCA.

69

70 **Methods**

71 *Settings and study design*

72 This is a retrospective study conducted on the island of Langeland, Denmark. Langeland covers
73 approximately 291 km² (about 60 km long and 10 km at the widest point) and has a population of about
74 12,000 of which one-third live in the city of Rudkøbing. During summer months the population grows
75 substantially (15). Rudkøbing has an EMS station with an ambulance and a paramedic in a non-transporting
76 EMS vehicle. Langeland has no local hospitals, but is bridge-connected to Funen, where there are two
77 hospitals that both have cardiac care units and one has invasive cardiac facilities.

78

79 *Emergency medical dispatch centre and AED network*

80 In Denmark, if the emergency medical dispatch centre receives a call and suspects cardiac arrest, the health
81 care professional follows a standardized national protocol to phone-assist the bystander in performing CPR.
82 Also, a two-tiered EMS system is activated following the dispatch of an ambulance and a physician-manned
83 vehicle. On Langeland, a paramedic is always activated when cardiac arrest is suspected.

84

85 *GPS system and volunteer first responders*

86 The VFRs in this study are citizens that undergo a European Resuscitation Council (ERC)-certified basic life
87 support (BLS) course and a course in emergency first aid. Afterwards they undergo yearly mandatory
88 training to renew their certificates. When the course is completed, the individual VFR downloads a
89 smartphone application (FirstAED), which must be manually activated, when the VFR is available for
90 dispatch.

91 The GPS-tracking system was introduced in April 2012. On Langeland, the system is activated during all
92 emergency calls, where an EMS is requested. Activation is followed by GPS localization and alert of the
93 nine closest VFRs within 5000 meters of the emergency site, who may choose to accept or reject the call. Of
94 all VFRs accepting the call, three are selected based on their location and the placement of the nearest AED.
95 Each of the VFRs is given a distinct role, of which one of the responders is guided to the nearest AED before
96 approaching the emergency site. The AEDs are placed in heated cabinets and when GPS-activated, the
97 cabinet turns on a blue flashlight and a siren alarm. Information about AED location and availability is
98 retrieved through the nationwide AED-network (www.hjertestarter.dk). The other two VFRs must
99 immediately rush to the emergency site and start CPR, assist the EMS staff, comfort bystanders etc. Figure 1
100 shows the activation of the GPS-tracking system.

101

102 *Variables of interest*

103 The main outcome variables of interest are response rates and response times for VFRs vs. EMS. The
104 secondary outcome is 30-day survival after OHCA in residential areas and on public locations.

105 Covariates of interest are location, bystander CPR, first documented rhythm, VFR arriving with AED before
106 EMS, bystander/VFR/EMS defibrillation and Cerebral Performance Category score.

107

108 *Study population*

109 The OHCA study population includes EMS-treated OHCAs that occurred on Langeland from 21st of April
110 2012 until 31th of December 2017. Location of cardiac arrest was defined according to the Utstein-style
111 recommended guidelines (16).

112 Patients with obvious late signs of death, non-OHCAs and OHCA due to non-medical causes (suicide,
113 trauma, accidents etc.) were excluded (16). Also, patients with OHCAs occurring in nursing homes were
114 excluded. Cardiac and non-cardiac causes of cardiac arrest were defined according to the 2015 updated
115 Utstein guidelines (17).

116

117 *Data collection*

118 Data was collected following the Utstein-recommendations for reporting resuscitation outcomes (16).
119 Information about the response times of EMS and VFRs was collected from the emergency medical dispatch
120 centre in the Region of Southern Denmark.
121 From April 2012 to September 2015 patient data retrieved by EMS personnel was filled out on paper reports,
122 which were systematically screened to identify OHCAs. From September 2015 EMS information was filled
123 out and stored electronically (Elektronisk Patient Journal), and therefore all journals reporting problems
124 involving airways/breathing/circulation were screened along with those reporting cerebral derangement
125 (unconsciousness, epileptic seizures etc.). To cross-check for missing OHCAs, the medical dispatch centre in
126 the Region of Southern Denmark provided a data extraction on all patients that had any information written
127 in the field “Cardiac Arrest”. Information about in-hospital treatment and survival was retrieved from
128 hospital records using each patient’s unique personal identification number (18).

129

130 ***Statistics***

131 The categorical variables will be presented as frequencies and percentages. Comparison between categorical
132 groups will be performed using the Pearson’s chi-square test or Fisher’s exact test, depending on sample
133 size. Continuous variables, e.g. response times, will be visually inspected for normal distribution and
134 displayed using mean (\pm standard deviations), and in group comparisons Student’s t-test or a one-way
135 analysis of variance (ANOVA) will be used, depending on the number of independent groups in the
136 comparison. If more than one VFR arrives at the emergency site, the shortest response time will be used.
137 This also applies if more than one EMS arrives to the emergency site. To describe non-normally distributed
138 continuous variables, medians with 25th and 75th percentiles will be presented. To perform group
139 comparisons between non-normally distributed variables, the non-parametric Mann Whitney U-test and
140 Kruskal-Wallis test will be used in cases of two or more group comparisons, respectively. The statistical
141 significance level is 5%. Analysis will be performed by use of STATA version 15 (StataCorp LP, College
142 Station, Texas).

143

144 ***Ethics and data protection***

145 The study was approved by The Danish Data Protection Agency (Journal no. 17/32047) and the Danish
146 Patient Safety Authority under the administration of Danish Health Authority (no. 3-3013-2848/1, ref.
147 LOSC). In Denmark, ethical approval is not necessary for this type of study.

148

149 **Results**

150 In 2012, 185 citizens of Langeland were registered as VFRs; in 2017 this number had slightly decreased to
151 170. During the 5½-year inclusion period, 96 AEDs were registered on Langeland (15).

152 The GPS-tracking system was activated in 2774 emergency calls (Figure 2). In 101 calls (4%) none of the
153 VFRs responded. In 2662 calls (96%) at least one VFR arrived to the emergency site, and in 2266 of these
154 (85%), the VFR arrived before the EMS. In 1745 of 2662 cases (66%) the VFR brought an AED to the
155 emergency site before EMS arrival (Figure 2). In nearly two-thirds of the 2662 emergency calls, all three
156 VFRs arrived to the emergency site (n=1648, 62%) (Appendix I).

157
158 The median response time for all VFRs (n=2662) was 4 minutes and 46 seconds (Table 1). The response
159 time for VFRs bringing an AED to the emergency site (n=2380) was 6 minutes and 21 seconds. In
160 comparison, the response time for EMS (n=2763) was 10 minutes and 13 seconds, which was significantly
161 higher compared with both VFR groups (P <0.0001) (Table 1).

162
163 We identified 243 patients with presumed OHCA (Figure 3), and further assessment revealed that 112 were
164 true OHCAs. Of these, 65 OHCAs occurred in residential areas (58%) and 17 OHCAs occurred in public
165 areas (15%). Thirty patients were excluded as they were located in nursing homes or had unknown/imprecise
166 location of cardiac arrest (Figure 3). Table 2 shows the demographic and survival data concerning the 82
167 patients of relevance. The two groups were comparable in age, sex distribution and cardiac disease.
168 Comorbidity occurred more frequently in patients from residential areas than in those from public areas.
169 Thirty-day survival in OHCA patients from residential areas was 15% (10 of 65) vs. 24% (4 of 17) in OHCA
170 patients from public areas (p=0.47) (Table 2).

172 **Discussion**

173 In this retrospective study, we found that a smartphone GPS-tracking system that locates and activates VFRs
174 results in a 96% response rate and significantly reduces VFR response times compared to response times for
175 EMS. In more than four of five cases a VFR arrives to the emergency site before the arrival of the EMS. Our
176 observations may suggest that the 30-day survival was higher in both residential and public areas, in
177 comparison with the results reported in earlier OHCA studies.

178 In Denmark, bystander CPR has increased substantially, probably due to large-scale public initiatives in
179 promoting BLS training and increased awareness concerning early action during cardiac arrest (2, 3).
180 Bystander defibrillation, on the other hand, mainly takes place at public cardiac arrests, and defibrillation in
181 residential areas occurs in less than 5% in most register studies (2, 19, 20). Recent studies have evaluated the
182 use of different mobile devices to activate citizens and health professionals and facilitate early BLS in cases
183 of presumed OHCA. In a randomized controlled trial, Ringh et al found that 65% of VFRs within a 500 m
184 diameter accepted the emergency call and 59 % of these arrived before EMS, which lead to a significant
185 increase in bystander CPR (13). In an observational study, Caputo et al found that using a mobile application
186 to activate VFR increased the response rate up to 70 % compared to 15% using a text-message activating

187 system (21). In contrast, a survey among VFRs using the PulsePoint system reported that 23% responded to
188 the notification but only 11% arrived at the scene (22). In our study a 96% response rate was found, and in
189 most of these (85%) the VFR arrived before the EMS. The reasons for the large variation in VFR response
190 rates observed in different studies are unknown. However, we may speculate that different levels of
191 education and training could result in varying commitment among VFRs; as in this study, the first two
192 studies required updated ERC-certification in BLS with annual mandatory certificate renewal (13, 21), which
193 was not the case in the latter study (22). Also, response rates may vary due to differences in the geographical
194 location and the degree of urbanization in the different studies. Perhaps, in rural areas a stronger feeling of
195 commitment among the local citizens to join a VFR network exists, because AEDs are less common and
196 EMS response times are longer than in densely populated areas.

197 The number of dispatched VFRs in earlier studies varies markedly. In three different studies (12-14), VFRs
198 within 500-1000 m of the emergency site were activated. This may be suitable in an urban setting with a high
199 population density. However, it may be difficult to recruit VFRs in a rural area, with longer distances to the
200 nearest available EMS, which may also require that VFRs use transport vehicles to reach the emergency site.
201 This issue has been addressed by Auricchio et al, where VFRs covered a median distance of 1196 m to reach
202 the emergency sites (23). The VFRs travelled with an average speed of 24 km/h, suggesting the usage of
203 motorized vehicles. The study, however, reported a 100% response rate among eligible VFRs, which has
204 been yet unseen. Also, the study could not describe the alert strategy in selecting VFRs to either locate the
205 nearest AED or to reach the site immediately, nor could they describe the number of AEDs arriving to the
206 site before EMS. The island of Langeland consists mainly of rural countryside, and to reach a wider VFR
207 and AED coverage, the smartphone GPS-tracking system in this study used a 5000 m radius. This did not
208 appear to reduce VFR response rates in this study, where at least two of three VFRs responded to the
209 emergency call in the majority of emergency calls (Appendix I). Moreover, only three VFRs were dispatched
210 per emergency call, which is a relatively low number compared to other studies (12-14, 24, 25), but neither
211 this appeared to affect the response rates among VFRs (Appendix 1). Perhaps, this is an important
212 consideration in the efforts to optimize the response rate for VFRs. If a high number of VFRs arrive to the
213 emergency site only to find that other VFRs are already present, they may feel demotivated and become less
214 eager to accept future calls. Of course, this is speculative, but should perhaps be a concern when designing
215 future studies in this field.

216 So far, only one study has compared VFR response times with the conventional EMS response times (24).
217 Berglund et al used a smartphone application to activate CPR-trained lay volunteers in all cases of suspected
218 OHCA. A significant reduction in response time (6:17 minutes for first arriving responder versus 9:36
219 minutes for EMS) was found. However, the study only covered greater Stockholm and was not active during
220 night hours (24). This issue is of major importance when evaluating the actual reduction in time to CPR and
221 defibrillation. It is well established that survival after OHCA is extremely time-sensitive, and the minute-to-

222 minute mortality risk until defibrillation can be reduced to 3-4 % per minute with early CPR (26). In the
223 present study, we demonstrate that the GPS-tracking system has the potential to increase rates of bystander
224 CPR as well as to reduce the time to CPR in OHCA patients, which ultimately may lead to improved
225 survival.

226

227 Cardiac arrest in residential areas comprises three-quarters of OHCAs in most studies (6, 10). Yet, survival
228 in these patients remains low compared to cardiac arrest in public areas. The reasons for the discrepancy is
229 multifactorial; cardiac arrest in residential areas are more frequently unwitnessed, have lower rates of
230 bystander CPR, the population is older with more comorbidity and has more often non-shockable rhythm (2,
231 11). Also, the number of available on-site AEDs is skewed in favour of public locations (2), which further
232 complicate AED use in residential areas. A study by Hansen et al demonstrated a higher frequency of
233 shockable first rhythm from AED data compared with EMS data (27), perhaps due to shorter time from
234 collapse to rhythm analysis. In the study by Zijlstra et al, a text-message based alert system resulted in a
235 reduction in time to defibrillation in residential areas, compared with defibrillation by conventional EMS
236 personnel (14). However, the number of VFRs actually reaching the site was unknown and the study did not
237 evaluate the prognostic impact (14). In 2014, only 0.8% of residential OHCAs in Denmark underwent
238 bystander defibrillation (10), which, in this study took place in 13% of OHCAs in private homes. Also, we
239 demonstrated an increase in 30-day survival after OHCA in both residential and public areas, with a
240 combined survival of 17% (14 out of 82 patients), which is markedly higher compared to other studies in this
241 field (10, 28, 29). It remains uncertain whether these findings is a direct effect of the VFR efforts, however,
242 the rapid VFR response rates and response times combined with early AED use may be favourable for opting
243 early BLS and creating better survival outcomes.

244

245 *Strengths and limitations*

246 A strength of this study is the use of a well-established national AED-register that provides VFRs with
247 updated information taking into account the specific availability of AEDs in the nearby area (23). It is also
248 novel for being the first to provide VFRs with distinct roles, which strengthens team structure during
249 emergency calls. Unlike other studies in this field our study is not register-based, and is characterized by the
250 thorough case ascertainment to identify OHCA subjects in the inclusion period. Also, we cross-checked
251 OHCA data by extracting information from the dispatch centre in the Region of Southern Denmark and
252 thereby identified further two missing OHCA subjects. The civil registration system used in Denmark
253 provides a unique opportunity to identify and collect patient data by matching them across different
254 electronic systems, adding even further to data completion in this study (18). However, the study has several
255 limitations. It is a single-centre study conducted retrospectively with a small number of OHCAs, and the
256 study is not designed to evaluate causality between the smartphone GPS-tracking system used and its impact

257 on survival after cardiac arrest.. Also, this study has a 5½-year inclusion period, and we cannot account for
258 an expected time-dependent rise in 30-day survival after cardiac arrest; there may have been additional
259 citizen BLS training programs and other public initiatives, as well as improvements in prehospital and in-
260 hospital advanced treatment that may have influenced the increase in 30-day survival. This remains
261 speculative.

262

263 **Conclusion**

264 In this retrospective study, we found that the use of a smartphone GPS-tracking system to alert and dispatch
265 trained VFRs during emergency calls results in a high VFR response rate and significantly reduces response
266 times for VFRs compared to EMS response times. In more than four out of five cases, a VFR arrived to the
267 emergency site before EMS. Finally, our results show a trend towards improved 30-day survival in OHCA
268 patients, however; this calls for further causal research in this field.

269

270

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275

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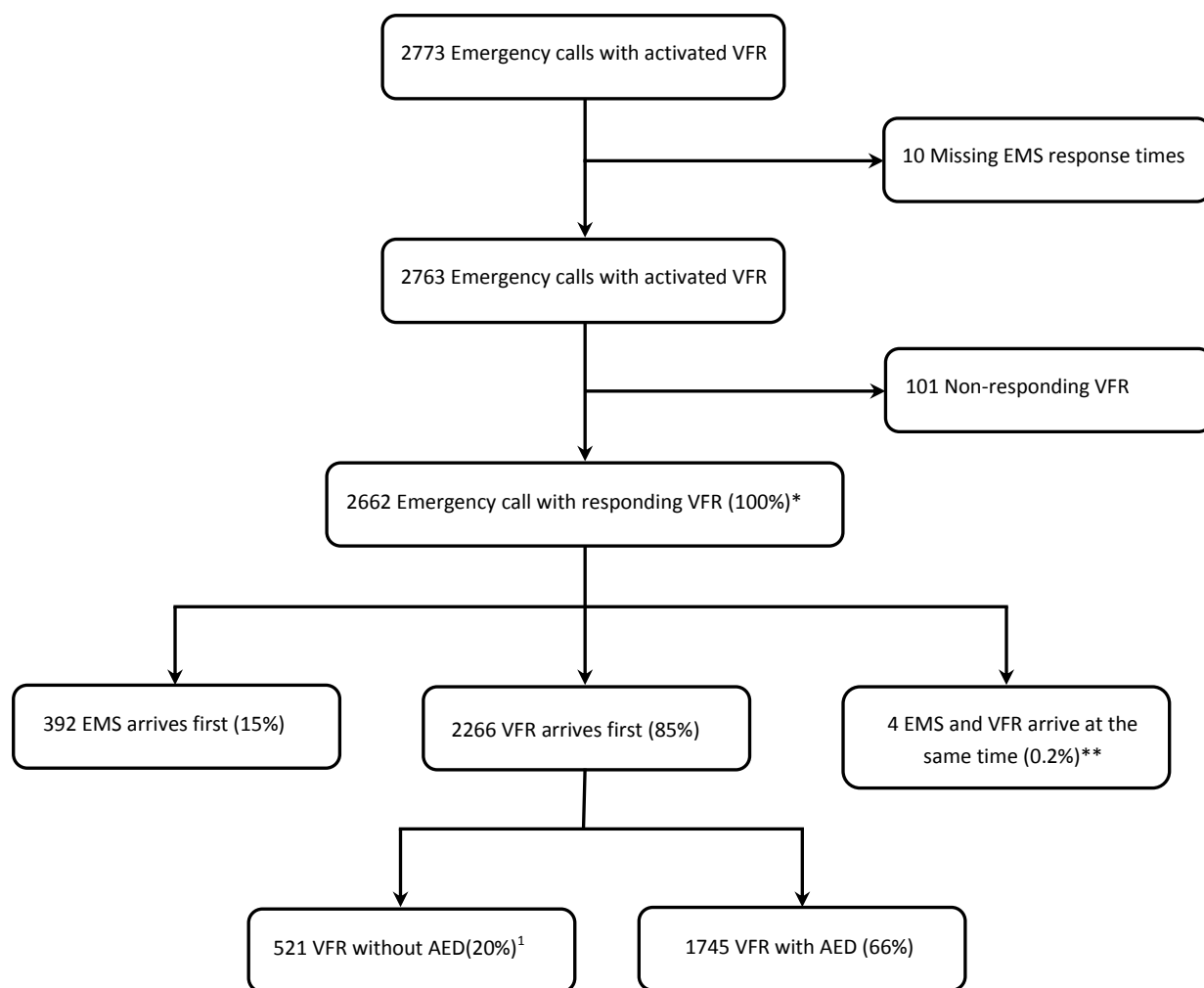


Figure 1. Flow-chart showing the number of emergency calls with activation of volunteer first responders (VFR). EMS: Emergency medical service. * 2380 brought an AED. ** I Metode: denne grupper kommer "EMS arrives first"¹ Responstid

Table 1. Response times for the volunteer first responders compared with EMS.

	All VFRs (n=2662)	All VFRs with an AED (n=2380)	VFR with AED on- site before EMS (n=1745)	EMS (n=2671)	P value
Time (min:sec), median (IQR)	4:46 (3:16-6:52)	6:21 (4: 29-8:49)	4:32 (3:07-6:21)	10:19 (6:19-15:44)	<0.0001

AED: Automated external defibrillator. EMS: Emergency medical Service. IQR: Interquartile range. VFR: Volunteer first responder.

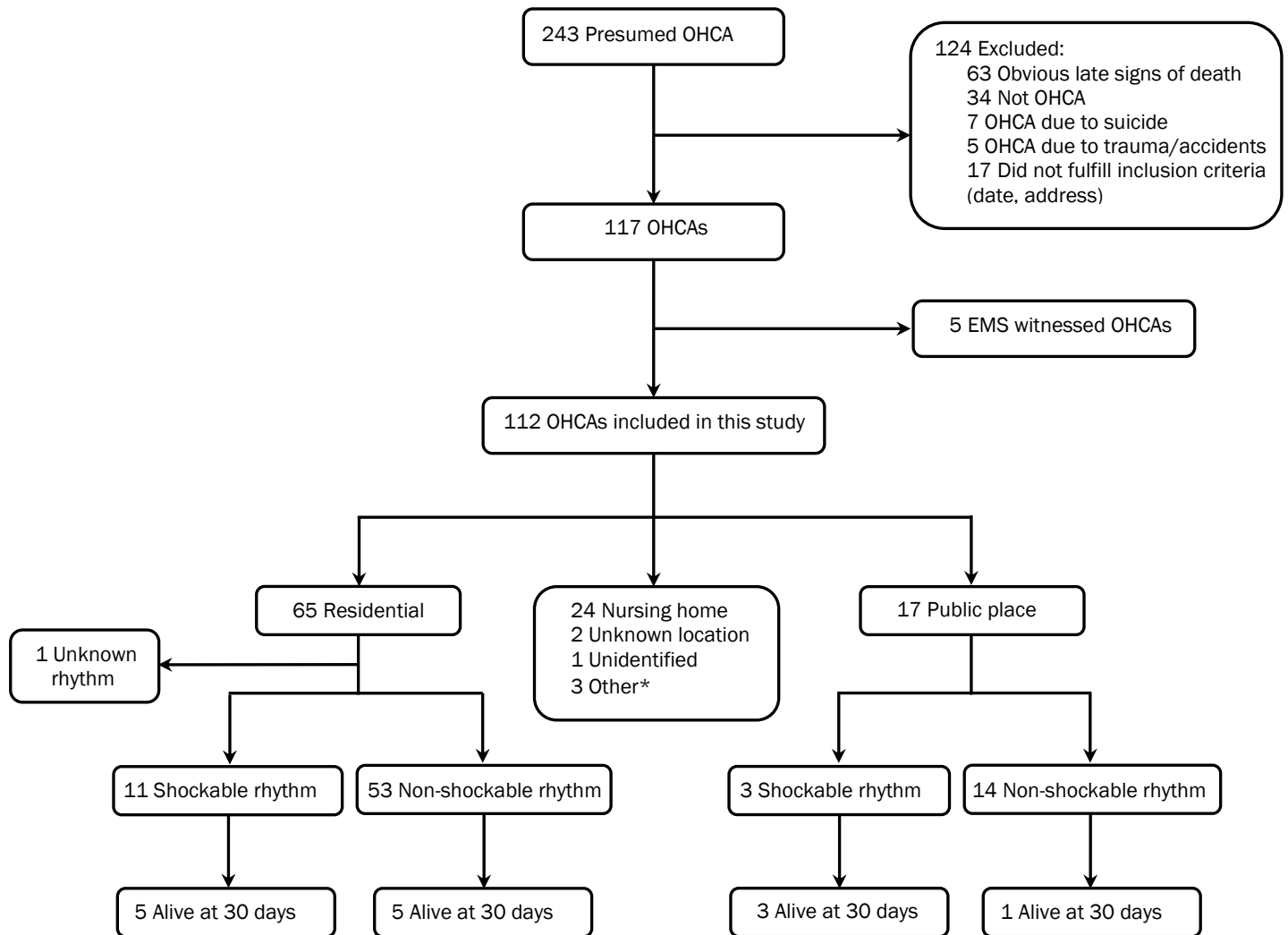


Figure 2. Flow-chart showing the inclusion-exclusion process in identifying OHCA.
OHCA: Out-of-hospital cardiac arrest

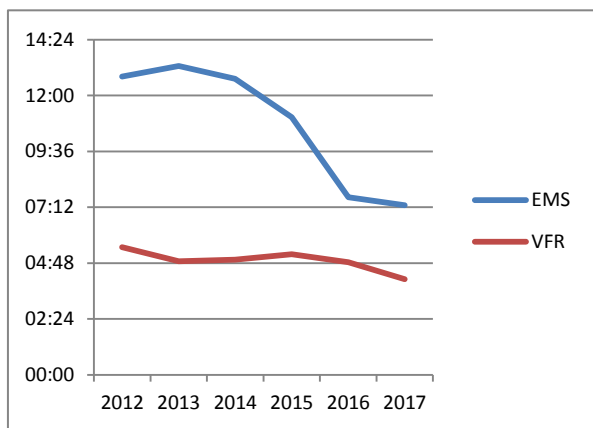


Figure 3. Response times for VFR and EMS in the years 2012-2017.
 EMS: Emergency medical service. VFR: Volunteer first responder.

(Kun til eget brug %artikel)	EMS	VFR
2012 (N=239)	12:49	05:29
2013 (N=376)	13:16	04:53
2014 (N=417)	12:43	04:57
2015 (N=324)	11:04	05:11
2016 (N=743)	07:38	04:50
2017 (N=572)	07:17	04:06

Table 2.	Residential area	Public place
	(N=65)	(N=17)
Age, mean (SD)	71 (13)	68 (13)
Male sex, no. (%)	46 (65)	13/ (81)
Presumed cardiac cause, no. (%)	33 (51)	13 (76)
Witnessed, no. (%)	32 (49)	11 (65)
Bystander CPR, no. (%)	53 (82)	17 (100)
Shockable first rhythm, no. (%)	11 (17)	3 (18)
Defibrillation before EMS, no. (%)	4 (6)	2 (12)
Defibrillation by EMS, no. (%)	7 (11)	1 (6)
VFR activated, no. (%)	54 (83)	16 (94)
VFR arrives before EMS, no. (%)	43 (81)	14 (88)
VFR with AED arrives before EMS, no. (%)	36 (67)	11 (69)
Pre-arrest comorbidity, no. (%)		
Ischemic heart disease	11/59 (19)	1/13 (8)
Diabetes	11/59 (19)	2/13 (15)
Hypertension	29/58 (50)	4/13 (31)
EF \leq 45%	10/59 (17)	0/12 (0)
COPD	22/59 (37)	0/12 (0)
Chronic kidney disease	3/59 (5)	0/12 (0)
Prior stroke	7/59 (12)	0/12 (0)
Psychiatric disease	8/57 (14)	1/12 (8)
Active cancer	6/59 (10)	0/12 (0)
ROSC at hospital arrival, no. (%)	20 (31)	5 (29)
Alive at 30 days, no. (%)	10 (15)	4 (24)