Temporal Trends in Coverage of Historical Cardiac Arrests Using a Volunteer-Based Network of Automated External Defibrillators Accessible to Laypersons and Emergency Dispatch Centers

Running title: Malta Hansen et al; Volunteer-based AED Network

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Abstract

Background—Although increased dissemination of Automated External Defibrillators (AEDs) has been associated with more frequent AED use, the trade-off between the number of deployed AEDs and coverage of cardiac arrests remains unclear. We investigated how volunteer-based AED dissemination affected public cardiac arrest coverage in high- and low-risk areas.

Methods and Results—All public cardiac arrests (1994–2011) and all registered AEDs (2007–2011) in Copenhagen, Denmark, were identified and geocoded. AED coverage of cardiac arrests was defined as historical arrests ≤100 meters from an AED. High-risk areas were defined as those with ≥1 arrest every 2 years and accounted for 1.0% of the total city area. Of 1864 cardiac arrests, 18.0% (n=335) occurred in high-risk areas throughout the study period. From 2007–2011, the number of AEDs and the corresponding coverage of cardiac arrests increased from 36 to 552 and from 2.7% to 32.6%, respectively. The corresponding increase for high-risk areas was from 1 to 30 AEDs and coverage from 5.7% to 51.3%, respectively. Since the AED network establishment (2007-2011) few arrests (n=55) occurred ≤100 meters of an AED with only 14.5% (n=8) being defibrillated before EMS arrival.

Conclusions—Despite the lack of a coordinated public access defibrillation program, the number of AEDs increased 15-fold with a corresponding increase in cardiac arrest coverage from 2.7% to 32.6% over a 5-year period. The highest increase in coverage was observed in high-risk areas (from 5.7% to 51.3%). AED networks can be used as useful tools to optimize AED placement in community settings.

Key words: cardiac arrest, automated external defibrillator, cardiopulmonary resuscitation, defibrillation
Introduction

Automated External Defibrillators (AEDs) can increase survival markedly after out-of-hospital cardiac arrest, and can safely and effectively be used by laypersons.1-9 However, in order to increase survival, AEDs need to be used within minutes of the event and, thus, be close to the victim, easily locatable and accessible to bystanders.3-6,10 The highest survival rates associated with AED use are from settings where the above conditions are met, such as casinos and airports.3-5

In real-life settings, an increased focus on public access defibrillation has led to widespread AED dissemination.7-9,11-15 Whereas an increased AED dissemination has been associated with higher AED use, the trade-off between the number of deployed AEDs and coverage of cardiac arrests in real-life settings remains unclear.8,11 Furthermore, AEDs are often privately owned or deployed as a result of local political initiatives, with no underlying strategy in terms of covering high-risk sites of cardiac arrest or linkage to the Emergency Medical Services (EMS).7-9,11-13,15-18 Accordingly, due to the lack of information regarding AED location, accessibility, and viability at the time of cardiac arrest, Emergency Medical Dispatch Centers (EMDs) are often unable to guide bystanders to AEDs before EMS arrival.7,8,12,13,15,19 While the American Heart Association (AHA) and the European Resuscitation Council (ERC) recommend communities to establish AED registration providing real-time validated information on AED location and viability as well as linkage to EMD, the implementation and follow-up of such a system has not yet been described.12,15,20-22

The aim of this study was two-fold: (1) to describe a nationwide volunteer-based AED network linked to all EMDs, with continuously updated and validated information regarding AED viability, location and accessibility and (2) to evaluate the trade-off between the number of
deployed AEDs and AED coverage of public cardiac arrests in high- and low-risk areas in a city center, following unguided, widespread AED dissemination during 2007-2011.

Methods

The Danish Nationwide AED Network

Since 2007, AEDs available for public access defibrillation have been able to be registered online in a Danish AED network (www.hjertestarter.dk). Registration with the network is voluntary. Since 2010, the Danish Health and Medicines Authority together with a majority of AED vendors, have recommended all publicly available AEDs should be registered with the network. The network was established in Copenhagen in 2007 and became nationwide and accessible to all five EMDs in Denmark in 2010.

Upon registration, the AED owner provides all relevant information including (1) name and contact information for the person responsible for the AED, (2) exact address where the AED is located, (3) hours when the AED is accessible for public access defibrillation, including during vacation days/holidays, (4) the AED’s registration number, manufacturer, type, model, (5) AED status such as when the batteries and electrodes should be checked and replaced, (6) date of inauguration. The person responsible then signs a contract through which they certify that it is their responsibility that all AED information is correct and valid at all times. To validate the information, an employee at the network contacts the owner by telephone within a few days of registration. The AED only becomes active in the network once all information has been validated.

Once the AED is active in the network (http://www.hjertestarter.dk/Service-Pages/InEnglish), its location and hours of accessibility can be seen by any person who visits the website. The EMDs have access to more detailed information, such as contact information to the
AED location and persons responsible for the AEDs. All information is validated every six months through a telephone call from an employee at the AED network to the persons responsible for the AED. If it is not possible to validate the information, the AED is removed from the network. All EMDs in Denmark have real-time information regarding all AEDs in the network, updated every three hours.

**AED Network and Emergency Dispatch Center in Copenhagen**

If a cardiac arrest is presumed, the dispatcher follows an algorithm which includes guiding bystanders to perform cardiopulmonary resuscitation (CPR), and identifying nearby AEDs available for public access defibrillation. The software (Logis-CAD) in the EMD automatically identifies and shows the dispatcher all accessible AEDs reachable within 1½-min of the cardiac arrest location (depending on type of terrain, whether the bystander is able to drive to the AED location, etc.), in accordance with AHA recommendations. If the AED is on-site, the dispatcher guides bystanders to retrieve the AED. If the AED is not on-site but within reachable distance of the cardiac arrest and more than one bystander is present, the dispatcher guides one bystander to retrieve the AED and the other bystanders to perform CPR. The dispatcher can also contact the AED location and request that the AED be delivered to the location of cardiac arrest, if possible. When the EMD refers to an AED, the AED is automatically deactivated from the AED network, and remains so until the owner has certified that the AED is viable for use.

When an AED has been applied to a patient, it is transported by EMS personnel to the EMD in order to retrieve data and change electrodes. The electrocardiogram and data recorded by the AED are then sent electronically to the admitting hospital. The AED is returned to the owner with a new set of electrodes within 24 hours of the cardiac arrest and all costs are covered by the Copenhagen EMS.
Study Setting

The municipality of Copenhagen has a resident population of approximately 600,000 and covers 97 km² (60 square miles). The Copenhagen EMS is a two-tiered system comprising basic life support provided by ambulances equipped with defibrillators and advanced life support provided by physician-staffed mobile emergency care units. In the event of cardiac arrest, both tiers of response are activated simultaneously from the EMD.

Study Population

The study population selection, inclusion and exclusion criteria followed the Utstein template for reporting out-of-hospital cardiac arrests, as done previously. A cardiac arrest was defined as apnoea (or abnormal respiration) and the absence of consciousness, identified by EMS personnel or physician. The study population comprised all out-of-hospital cardiac arrests of presumed cardiac cause in public locations, in Copenhagen, Denmark, during 1994–2011. Due to incomplete data registration in 1999, we did not identify cases with out-of-hospital cardiac arrest in that year. The presumed cause of cardiac arrest was adjudicated by the EMS physician at the scene. Cardiac arrests with obvious late signs of death (eg. rigor mortis) and with obvious non-cardiac cause of cardiac arrest were excluded. Only patients who were eligible for an on-site resuscitation attempt by the EMS personnel or physician were included in the study. Public locations were defined as all areas accessible to the general public, including all outdoor locations, public transportation sites, schools, outpatient clinics, and commercial and civic establishments. Cardiac arrests with missing information regarding exact location of arrest were excluded from the study.

Data from each cardiac arrest was systematically and prospectively recorded by the physician at the scene following the Utstein template for reporting out-of-hospital cardiac
arrests. The following information was included for all cardiac arrests in this study: date, time, and exact address of cardiac arrest; type of location; first-observed cardiac rhythm (non-shockable rhythm [asystole or pulseless electrical activity] or shockable rhythm [ventricular fibrillation or – pulseless ventricular tachycardia]); time interval from the dispatch of vehicle to arrival at scene (response time). The following variables were available for cardiac arrests during 2008–2011: whether the collapse was witnessed and whether bystander CPR was initiated before EMS arrival. Information regarding AED use (defined as AED applied to patient regardless of defibrillation) and AED defibrillation before EMS arrival was obtained through hospital charts provided by EMS or emergency room physician.

Information on patients’ survival status (dead or alive) 30 days after date of cardiac arrest was obtained from the Central Population Registry. Time of cardiac arrest was divided into daytime (8:00-15:59), evening (16:00-23:59) and nighttime (00:00-07:59).

Study Design
For this cohort study, data was prospectively collected and entered in the registry; the study was designed retrospectively. The exact locations of cardiac arrests and AEDs were geographically coded in a coordinate system through a geographic information system (X-Point) and marked on a digital city map, as done previously. The coordinate system is the European Grid System, a defined and harmonized grid net for Europe with standardized location and size of grid cells. We used SAS statistical software package, version 9.2 (SAS Institute Inc., Cary, NC, USA) to count all cardiac arrests and AEDs in every 100m x 100m (109.4yd x 109.4yd) grid cell in the study area.

Definition of High-risk and Low-risk Areas of Cardiac Arrest
To assess how large a proportion of the study population would potentially benefit from AED
deployment in high- or low-risk areas (trade-off), we divided the study area in (1) areas with a high risk, (2) low risk or (3) no cardiac arrests during the study period, on the basis of the locations of all cardiac arrests (1994–2011). Grid cells with > 7 cardiac arrests during the whole study period (≥1 cardiac arrest every 2 years), were defined as high-risk areas, in accordance with ERC 2005 guidelines, the Public Access Defibrillation (PAD) trial, and other studies.\textsuperscript{6,16,30}

Grid cells with 1-7 cardiac arrests were defined as low-risk areas. Grid cells without any cardiac arrests were defined as areas with no cardiac arrests.

**Analysis of Coverage of Historical Cardiac Arrests**

AED coverage of historical cardiac arrests was calculated using location of all public cardiac arrests during 1994–2011, in relation to location of AEDs linked to the EMD, according to year of AED deployment (2007–2011). All cardiac arrests from 1994–2011 were counted and then, for each year from 2007–2011, the percentage of those arrests that would have been covered by an available AED during that year was calculated. It was assumed that 1 AED could provide coverage for all cardiac arrests in a 100m x 100m (109.4yd x 109.4yd) grid cell based on the estimate that an AED can be transported 100m by bystanders in a 1½-min brisk walk, in accordance with AHA recommendations and previous studies.\textsuperscript{11,14,16,20}

**Analysis of Prospective Coverage of Cardiac Arrests**

For cardiac arrests that occurred after the implementation of the AED network (2007–2011), AED coverage of cardiac arrests was also calculated prospectively. Cardiac arrests were considered covered by an AED, if an AED had been deployed ≤100 m (109.4 yd) from the cardiac arrest location and prior to the cardiac arrest; and covered by an accessible AED, if the cardiac arrest was covered by an AED registered as accessible when the cardiac arrest occurred.\textsuperscript{14}
Statistical Analysis

Continuous variables are presented as medians with Q1-Q3 except for the variable “response time” which is presented as means with standard deviations. Continuous variables were compared using Wilcoxon-Mann-Whitney test except for the variable “response time” which was compared using the independent t-test. Discrete variables were compared with the χ²-test or Fisher’s exact test.

A χ²-test was employed to test for temporal changes in the proportion of cardiac arrests per year that occurred in the identified high-risk areas (grid cells). AED coverage of cardiac arrests is presented as (1) for all areas: percentage of all cardiac arrests in public locations covered by an AED; (2) for high-risk areas: percentage of all cardiac arrests in high-risk areas covered by an AED; (3) for low-risk areas: percentage of all cardiac arrests in low-risk areas covered by an AED. Since cardiac arrest in public locations is a rare event, we assumed it followed the Poisson distribution, and confidence intervals for coverage of cardiac arrests were calculated accordingly. Temporal changes in AED coverage and use were assessed with the Cochran-Armitage trend test; exact permutation was used when appropriate. We used Poisson regression analyses to assess temporal trends in incidence of cardiac arrests, based on changes in numbers of cardiac arrests per 100 000 persons living in the study area per year.

The association between location of cardiac arrest (high- or low-risk area) and shockable heart rhythm as first-recorded rhythm was assessed using logistic regression analyses. For analyses of cardiac arrests during 1994–2011, the fully adjusted model included age, sex and response time. For analyses of cardiac arrests during 2008–2011, the fully adjusted model included age, sex, response time, whether the arrest was witnessed, and whether the patient received bystander CPR before EMS arrival. Model assumptions (linearity of continuous
variables and lack of interactions) were tested and found to be valid unless otherwise addressed. Associations are presented as odds ratios (ORs) with 95% confidence intervals (CI).

All analyses were performed using the SAS statistical software package, version 9.2 (SAS Institute Inc., Cary, NC, USA) and R version 2.15.1 (R Core Team (2012)). For all analyses, a two-sided p-value <0.05 was considered statistically significant.

**Ethics**

The study was approved by the Danish Data Protection Agency (No. 2008-41-2685.). No ethical approval is required for retrospective registry studies in Denmark.

**Results**

**Cardiac Arrests**

The population selection is depicted in Figure 1. A total of 1864 cardiac arrests occurred in public locations during the study period (1994–2011). Of these, 18.0% (n=335) occurred in high-risk areas. The proportion of cardiac arrests that occurred in the identified high-risk areas during each year did not change significantly (1994–2011, p=0.48) (Figure 2). High-risk areas accounted for 1.1% of the city area.

**AEDs**

Since the inauguration of the Danish AED network, the total number of registered AEDs increased 15-fold (from 36 in 2007 to 552 in 2011 [5.7 AEDs per Km²], Table 1) and the number of AEDs in high-risk areas of cardiac arrest increased 30-fold (from 1 in 2007 to 30 in 2011). The number of AEDs increased 15-fold in areas with low risk or no cardiac arrests, from 21 in 2007 to 318 in 2011 and from 14 in 2007 to 204 in 2011, respectively. The corresponding numbers of AEDs per Km² in 2011 were 30.0, 9.6 and 2.7 in areas with high, low risk, and no
cardiac arrests, respectively (Figure 3).

By 2011, 552 registered AEDs covered 15.5% of the total city area. In total, 5.4% (n=30) of all AEDs were placed in high-risk areas while most AEDs (57.6%, n=318) were placed in low-risk areas or areas with no cardiac arrests (37.0%, n=204).

Of the AEDs deployed in high-risk areas, most (n=14) were placed in offices and only few in hotels (n=3), at train stations (n=2), or in large shopping malls (n=1).

Supplemental Table 1 shows the distribution of AEDs according to type of location in areas with high-, low-risk and no cardiac arrests, by December 31, 2011.

AED Dissemination and Coverage of Historical Cardiac Arrests

In total, AED coverage of cardiac arrests increased from 2.7% (n=51) in 2007 to 32.6% (n=608) in 2011 (Figure 4). The increase in coverage differed in high- and low-risk areas: From 2007 to 2011, coverage increased from 5.7% (n=19) to 51.3% (n=172) in high-risk areas and from 2.1% (n=32) to 28.5% (n=436) in low-risk areas, respectively. Overall, AEDs in high-risk vs. low-risk areas covered three times more cardiac arrests per AED during the whole study period (5.7 vs. 1.9 cardiac arrests per AED).

Assuming that one AED would cover all cardiac arrests in every grid cell, an estimated additional 81 AEDs would be necessary to cover the remaining high-risk areas, or roughly 3 times as many as currently deployed.

AED Dissemination and Prospective Coverage of Cardiac Arrests

A total of 474 cardiac arrests occurred after the AED network was established (2007–2011). Coverage of cardiac arrests during this period (only assessing AEDs deployed prior to cardiac arrests) was similar to coverage of historical cardiac arrests (1994–2011) (Supplemental Figure 1). There was a significant increase in coverage (from 4.0% [n=4] in 2007 to 34.9% [n=38] in
2011, p for trend < 0.0001) and coverage by an accessible AED at the time of cardiac arrest (from 3.0% \([n=2]\) in 2007 to 24.8% \([n=27]\) in 2011, p for trend < 0.0001).

**AED Use before EMS Arrival and Survival**

A total of 55 cardiac arrests covered by an accessible AED at the time of cardiac arrest were identified (Table 2). AED defibrillation before EMS arrival was associated with improved 1-day and 30-day survival; for AED defibrillation vs. no defibrillation, 1-day survival was 100.0% vs. 42.6%, \(p=0.004\), respectively; 30-day survival 87.5% vs. 19.2%, \(p=0.0004\), respectively. AED use before EMS arrival increased from 0.0% \((n=0)\) in 2007 to 25.0% \((n=6)\) in 2011, although not significantly \((p=0.08)\).

**Incidence of Cardiac Arrests**

Overall, there was a slight decrease in the number of cardiac arrests per year (0.96/100 000 per year, \(p<0.0001\)), as also observed in other studies in Denmark.\(^{19}\) The same pattern was observed for cardiac arrests in high-risk \((0.98/100 000/\text{year}, p=0.04)\) and low-risk areas \((0.96/100 000/\text{year}, p<0.0001)\).

**Patient Characteristics in High-risk vs. Low-risk Areas**

Baseline characteristics are shown in Table 3. Overall, there was no significant difference in the proportion of patients with a shockable heart rhythm in high-risk vs. low-risk areas \((38.3\% \text{ vs. } 39.6\%, p=0.07; \text{unadjusted OR } 0.94 \text{ [95\%CI:0.72-1.22]; adjusted OR } 0.92 \text{ [95\%CI:0.71-1.22]}\).

**Other Analyses**

Due to a significant interaction with age \((p=0.04)\), analyses were stratified by age group. Patients < 40 years of age were less likely to have a shockable heart rhythm in high-risk than patients in low-risk areas \((\text{adjusted OR } 0.37 \text{ [95\%CI:0.14-0.98]}\)) whereas the remaining age groups did not show a significant difference between patients in high-risk vs. low-risk areas. For cardiac arrests
during 2008–2011, there was no significant difference in the proportion of patients with a shockable heart rhythm in high-risk vs. low-risk areas (unadjusted (OR 1.21 [95%CI;0.69-2.14]); adjusted (OR 1.25 [95%CI;0.67-2.34]).

Discussion

This study describes how a volunteer-based AED registry with real-time, validated information on AED location, accessibility, viability, and linkage to EMDs can serve to guide bystanders to nearby AEDs in case of a cardiac arrest, as well as a public health tool to optimize AED placement and use. Despite the absence of a strategic public access defibrillation program, the number of registered AEDs available for public access defibrillation in Copenhagen increased 15-fold, and coverage of historical cardiac arrests increased from 2.7% in 2007 to 32.6% during a 5-year period. By 2011, 15.5% of the study area was covered by an AED with a density of 5.7 AEDs per Km². The greatest increase was observed in high-risk areas (from 1 to 30 AEDs per Km²), increasing cardiac arrest coverage from 5.7% to 51.3% in these areas.

Although the overall coverage of cardiac arrests increased significantly, 94.6% of all AEDs were placed in areas with low risk or no cardiac arrests, in contrast to current guidelines that recommend targeting AED deployment at high-risk areas. Moreover, most AEDs in high-risk areas were in offices and not in previously identified high-risk locations, such as train/bus stations or large shopping malls.13,16 An association between increased AED dissemination, AED use, and survival after out-of-hospital cardiac arrest has previously been shown and our results are in accordance with such findings.8 However, uncoordinated AED implementation has been associated with a paradoxical placement of AEDs, with many AEDs in low-risk and few AEDs in high-risk areas of cardiac arrest, and therefore comes with a very low benefit and a very high
cost.\textsuperscript{8,11,13,16,31} Our prospective analysis of AED coverage supports this notion. Of the 474 cardiac arrests that occurred after the AED network was established (2007–2011), 55 were ≤100 of an accessible AED at the time of cardiac arrest (Table 2). Only 9 arrests had an AED applied before EMS arrival but with an increase in AED use from 0.0% (n=0) in 2007 to 25.0% (n=6) in 2011 and with a corresponding 30-day survival for AED defibrillation vs. no defibrillation of 87.5% vs. 19.2%. Several conditions could account for this. First, the majority of AEDs were deployed during the last two years of the study and in areas with few or no cardiac arrests. Second, most AEDs were only accessible during office hours and third, the EMD only started referring bystanders to the nearest AED in 2011.\textsuperscript{14} Fourth, the concept of public access defibrillation emerged during the last 10 years and medical-legal issues as well as fear could discourage bystanders of using AEDs. Nonetheless, there was a strong association between 30-day survival and AED use. Thus, unguided initiatives alone are not sufficient to achieve AED coverage of key areas in a community and authorities should monitor and complement these to optimize AED placement and use.\textsuperscript{11,13,16} An AED network can be used as a public health tool providing information to monitor existing AEDs and identify areas lacking AED coverage to guide future AED deployment, as encouraged by the AHA and the ERC.\textsuperscript{2,11,20,21} Mapping public cardiac arrests and current AED locations allows communities to monitor changes in the demography of public cardiac arrests and guide AED deployment accordingly. Moreover, locating an AED can be very time-consuming.\textsuperscript{12} The linkage between the AED network and the EMD allows dispatchers to locate the nearest accessible AED and decide how to get it to the cardiac arrest victim, thus relieving bystanders from further logistical obstacles.\textsuperscript{12,21}

High-risk areas comprised a small portion of the total city area (1.1%) but accounted for nearly 1/5 of all cardiac arrests. Coverage of all cardiac arrests in high-risk areas would require a
density of approximately 100 AEDs per Km² (81 additional AEDs) and limited efforts by authorities could cover the remaining high-risk areas. Notably, our study found no significant difference in the proportion of patients with a shockable heart rhythm in high- and low-risk areas. Both patient groups were thus equally likely to benefit from public access defibrillation. The decision to target AED deployment at high-risk areas may mainly rely on cost-benefit criteria (number of cardiac arrests likely to be treated per AED) rather than whether patients could benefit from defibrillation.

The main strengths of this study are that we report results from a volunteer-based nationwide AED registry linked to the EMD and EMS and available to the public, which holds real-time and validated information on AED location, accessibility, and viability. Such system has been recommended by guidelines for many years and can be implemented in other communities. Also, we report cardiac arrest data from a whole city over a period of 17 years, collected by one single EMS system. Our analyses add a long-term aspect to the paradigm that cardiac arrests in public locations are related to the movement patterns and underlying geographic epidemiology of the population, and are thus not simply random events.2,4,11,16 These findings are particularly valuable in the context of planning AED deployment and public access defibrillation programs – which is a long-term investment.20,21,32

Limitations

This study is limited by its observational nature. However, we believe complete and uniform registration of cardiac arrests were ensured by prospective data collection by the physician on the scene, following the standardized Utstein style for reporting out-of-hospital cardiac arrest.26 Accordingly, population characteristics are in agreement with previous studies.5,6,13,33,34

High-risk areas were defined in accordance with ERC 2005 guidelines and the PAD
It is important to consider that this definition does not take changing demographics into account. However, this study relates to cardiac arrests in public locations where demography is based on person flow (and not resident population) per grid cell per day. Previous studies, including from Copenhagen, have established an association between urban areas with a large person flow and a high risk of cardiac arrests and current guidelines recommend AED placement in high-risk areas based on this concept. We believe that data over a 17-year study period minimized the natural variability in the number of cardiac arrests occurring at a given site. The stable proportion of cardiac arrests occurring within the defined high-risk areas through the study period (Figure 2), as well as the similarity between AED coverage of historical as well as prospective cardiac arrests suggests that this definition and the subsequent interpretation of AED coverage are appropriate in our study. Our results might not be generalizable to other communities with different demographics and infrastructure, but we believe they can be used as guidance to communities seeking to implement AED programs.

Given the preponderance of clinical trial and observational evidence adopted by practice guidelines that defibrillation within minutes of cardiac arrest increases survival, our study was not designed to examine AED use or the effect of AED use on survival. Thus, the relationship between AED use, defibrillation and survival should be viewed as associations and not causality.

We reported only AEDs registered with the AED network, probably underestimating the potential of public access defibrillation in our study. However, the unregistered AEDs are neither readily locatable for persons who witness a cardiac arrest, nor to the emergency medical dispatcher and hence, the likelihood of AED use in such cases seems slight. Also, the unregistered AEDs are not validated in terms of location, accessibility and viability.

Future evaluations should assess other relevant aspects of AED implementation in the
community. For example how often AEDs were referred to by the EMD and whether it was easy to find; if bystanders were hesitant to use AEDs and if so, why; if used how bystanders reacted.

**Conclusion**

Despite the absence of a coordinated public access defibrillation program in Copenhagen the number of AEDs available for public access defibrillation increased 15-fold, with a corresponding increase in historical cardiac arrest coverage from 2.7% to 32.6% over a 5-year period. The greatest increase in coverage was observed in high-risk areas (from 5.7% to 51.3% [from 1 to 30 AEDs per Km²]), while 94.6% of all AEDs were placed in areas with low risk or no cardiac arrests. However, only few cardiac arrests were covered by an accessible AED at the time of cardiac arrest and only a small percentage of those AEDs were applied to and defibrillated a patient before EMS arrival. An AED network as presented here can be used to guide bystanders to the nearest accessible AED as well as to monitor existing, and guide future AED deployment in the community.

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Conflict of Interest Disclosures: The AED network is fully supported by TrygFonden with no commercial interests in the field of cardiac arrest. The authors have no conflicts of interest.

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Table 1. Distribution of Registered AEDs in Copenhagen 2007–2011

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<th>Year</th>
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<th>2011</th>
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<tr>
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<td>36</td>
<td>148</td>
<td>214</td>
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<td>11</td>
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<td>30</td>
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<td>in low-risk areas†</td>
<td>21</td>
<td>99</td>
<td>128</td>
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<td>318</td>
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<tr>
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<td>1.5</td>
<td>2.2</td>
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<td>7.1</td>
<td>9.6</td>
</tr>
<tr>
<td>In all areas with cardiac arrest</td>
<td>1.1</td>
<td>4.4</td>
<td>6.3</td>
<td>11.7</td>
<td>16.2</td>
</tr>
<tr>
<td>Per 100,000 inhabitants</td>
<td>6.0</td>
<td>24.7</td>
<td>35.7</td>
<td>66.3</td>
<td>92.0</td>
</tr>
</tbody>
</table>

Abbreviations: AED, automated external defibrillator. Sq Km, Square Kilometer.
* High-risk areas: grid cells with ≥1 cardiac arrest every 2 years.
† Low-risk areas: grid cells with ≥1 cardiac arrest that did not fulfill criteria for high-risk areas.
‡ 97 square kilometers (60 square miles).
Table 2. AED use and Survival.

<table>
<thead>
<tr>
<th>Cardiac Arrests ≤100m of accessible AED at the time of cardiac arrest irrespective of bystander CPR (n=55)</th>
<th>Total (n=55)</th>
<th>AED applied (n=9)</th>
<th>No AED applied (n=46)</th>
<th>p for difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-day survival</td>
<td>50.9 (28)</td>
<td>88.9 (8)</td>
<td>43.5 (20)</td>
<td>0.03</td>
</tr>
<tr>
<td>30-day survival</td>
<td>29.1 (16)</td>
<td>77.8 (7)</td>
<td>19.6 (9)</td>
<td>0.001</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total (n=55)</th>
<th>AED defibrillation (n=8)</th>
<th>No AED defibrillation (n=47)</th>
<th>p for difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-day survival</td>
<td>50.9 (28)</td>
<td>100.0 (8)</td>
<td>42.6 (20)</td>
</tr>
<tr>
<td>30-day survival</td>
<td>29.1 (16)</td>
<td>87.5 (7)</td>
<td>19.2 (9)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cardiac arrests ≤100m of accessible AED at the time of cardiac arrest who received bystander CPR before EMS arrival (n=31)</th>
<th>Total (n=31)</th>
<th>AED applied (n=9)</th>
<th>No AED applied (n=22)</th>
<th>p for difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-day survival</td>
<td>61.3 (19)</td>
<td>88.9 (8)</td>
<td>50.0 (11)</td>
<td>0.10</td>
</tr>
<tr>
<td>30-day survival</td>
<td>38.7 (12)</td>
<td>77.8 (7)</td>
<td>22.7 (5)</td>
<td>0.01</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total (n=31)</th>
<th>AED defibrillation (n=8)</th>
<th>No AED defibrillation (n=23)</th>
<th>p for difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-day survival</td>
<td>61.3 (19)</td>
<td>100.0 (8)</td>
<td>47.8 (11)</td>
</tr>
<tr>
<td>30-day survival</td>
<td>38.7 (12)</td>
<td>87.5 (7)</td>
<td>21.7 (5)</td>
</tr>
</tbody>
</table>

Abbreviations: AED, automated external defibrillator; EMS, Emergency Medical Services.

The table shows 1-day and 30-day survival for cardiac arrests ≤100m of an accessible AED according to whether patients had an AED applied or were defibrillated before EMS arrival during 2007–2011.
**Table 3.** Baseline Characteristics of Subjects with Out-of-hospital Cardiac Arrest in Public from 1994–2011

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Total (n=1737*)</th>
<th>In high-risk areas† (n=285)</th>
<th>In low-risk areas‡ (n=1452)</th>
<th>p value**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average age, y (Q1-Q3)</td>
<td>63.0 (24.0)</td>
<td>60.0 (29.0)</td>
<td>64 (24.0)</td>
<td>0.02</td>
</tr>
<tr>
<td>Men, average age, y ± (Q1-Q3)</td>
<td>60.0 (22.0)</td>
<td>59.0 (27.0)</td>
<td>61 (21.0)</td>
<td>0.09</td>
</tr>
<tr>
<td>Women, average age, y ± (Q1-Q3)</td>
<td>75.0 (22.0)</td>
<td>74.0 (26.5)</td>
<td>75 (23.0)</td>
<td>0.09</td>
</tr>
<tr>
<td>Male sex, n (%)</td>
<td>1315 (75.7)</td>
<td>1094 (75.3)</td>
<td>221 (77.5)</td>
<td>0.43</td>
</tr>
<tr>
<td>Mean response time, min ± SD†</td>
<td>5.0 ± 2.4</td>
<td>4.0 ± 2.1</td>
<td>5.2 ± 2.4</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>VF/pVT‡</td>
<td>684 (39.4)</td>
<td>109 (38.3)</td>
<td>575 (39.6)</td>
<td>0.67</td>
</tr>
<tr>
<td>Asystole</td>
<td>646 (37.2)</td>
<td>111 (39.0)</td>
<td>535 (36.9)</td>
<td>0.50</td>
</tr>
<tr>
<td>Pulseless Electric Activity</td>
<td>229 (13.2)</td>
<td>35 (12.3)</td>
<td>194 (13.6)</td>
<td>0.62</td>
</tr>
<tr>
<td>Other/unknown rhythm§</td>
<td>178 (10.3)</td>
<td>30 (10.5)</td>
<td>148 (10.2)</td>
<td>0.87</td>
</tr>
<tr>
<td>Survival after 30 days, n (%)</td>
<td>324 (18.7)</td>
<td>64 (22.5)</td>
<td>260 (17.9)</td>
<td>0.07</td>
</tr>
<tr>
<td>Time of cardiac arrest, n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daytime (8:00-15:59)</td>
<td>908 (52.3%)</td>
<td>129 (45.3)</td>
<td>779 (53.4)</td>
<td>0.01</td>
</tr>
<tr>
<td>Evening (16:00-23:59)</td>
<td>603 (34.7)</td>
<td>115 (40.4)</td>
<td>448 (33.6)</td>
<td>0.03</td>
</tr>
<tr>
<td>Nighttime (00:00-07:59)</td>
<td>226 (13.0)</td>
<td>41 (14.1)</td>
<td>185 (12.7)</td>
<td>0.45</td>
</tr>
</tbody>
</table>

**Abbreviations:** Q, Quartile. SD, Standard deviation.

*127 cases had an invalid identification number, mainly due to foreign resident status. These cases were excluded from baseline analysis due to missing information regarding age, sex and survival status.

†Interval between dispatch of vehicle to arrival at scene.

‡VF/pVT is ventricular fibrillation or pulseless ventricular tachycardia.

§Other/unknown rhythm includes pace rhythms and unknown rhythm.

‖High-risk areas: grid cells with ≥1 cardiac arrest every 2 years.

#Low-risk areas: grid cells with ≥1 cardiac arrest that did not fulfill criteria for high-risk areas.

**P value for difference between high- and low-risk areas.
Figure Legends:

**Figure 1.** Patient selection 1994–2011.

**Figure 2.** Cardiac Arrests in High-risk Areas According to Year. Legend: Proportion of cardiac arrests that occurred in the identified high-risk areas per year (≥1 cardiac arrest every 2 years), in Copenhagen, Denmark (1994–2011).

**Figure 3.** AEDs Available for Public Access Defibrillation per Square Kilometer (2007–2011). Legend: The figure shows the number of AEDs per Km², in Copenhagen, Denmark, according to year. The number of AEDs is shown for high-risk areas, low-risk areas, and all areas. On the basis of locations of cardiac arrests during 1994–2011, high-risk areas were defined as areas with ≥1 cardiac arrest every 2 years. Low-risk areas were defined as areas with ≥1 cardiac arrest that did not fulfill the criteria for high-risk areas.

**Figure 4.** AED Dissemination and Coverage of Historical Cardiac Arrests (2007–2011). Legend: AED dissemination (2007–2011) and coverage of historical cardiac arrests (1994–2011) are shown for high- and, low-risk areas, and all areas with cardiac arrests, in Copenhagen, Denmark. On the basis of locations of cardiac arrests during 1994–2011, high-risk areas were defined as areas with ≥1 cardiac arrest every 2 years. Low-risk areas were defined as areas with ≥1 cardiac arrest that did not fulfill the criteria for high-risk areas. A cardiac arrest was defined as covered if the AED was ≤100m of the cardiac arrest according to year of AED deployment.
8125 patients with out-of-hospital cardiac arrests registered by Copenhagen Mobile Emergency Care Unit physician during January 1, 1994–December 31, 2011*

866 excluded
Cardiac arrest of non-cardiac etiology†

7259 cardiac arrests of presumed cardiac etiology

58 excluded
unregistered location of cardiac arrest

7201 excluded
cardiac arrests in residential locations

1864 cardiac arrests in public locations included in analyses

*Due to incomplete data registration in 1999, we did not identify cases with out-of-hospital cardiac arrest in that year.
† Cardiac arrests were presumed to be of cardiac origin unless it was known to be caused by trauma, drowning, drug overdose, or asphyxia, in accordance with the Utstein Template for reporting out-of-hospital cardiac arrests.
Figure 3

- AEDs per sq Km, total city area
- AED per sq Km, in high-risk areas
- AED per sq Km, in low-risk areas

Year of AED deployment vs. AEDs per square kilometer.
Temporal Trends in Coverage of Historical Cardiac Arrests Using a Volunteer-Based Network of Automated External Defibrillators Accessible to Laypersons and Emergency Dispatch Centers

Carolina Malta Hansen, Freddy Knudsen Lippert, Mads Wissenberg, Peter Weeke, Line Zinckernagel, Martin H. Ruwald, Lena Karlsson, Gunnar Hilmar Gislason, Søren Loumann Nielsen, Lars Køber, Christian Torp-Pedersen and Fredrik Folke

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Table I online-only Data Supplement. Distribution of AEDs According to Type of Location and Area of Cardiac Arrest Following Unguided AED Placement in Copenhagen:

<table>
<thead>
<tr>
<th>AED Location</th>
<th>Total (n=552)</th>
<th>In high-risk areas (n=30)</th>
<th>In low-risk areas (n=318)</th>
<th>In areas with no cardiac arrests (n=204)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office</td>
<td>314</td>
<td>14</td>
<td>181</td>
<td>119</td>
</tr>
<tr>
<td>School, kindergarten, university</td>
<td>73</td>
<td>1</td>
<td>44</td>
<td>28</td>
</tr>
<tr>
<td>Sports facility</td>
<td>59</td>
<td>4</td>
<td>36</td>
<td>19</td>
</tr>
<tr>
<td>Theater, museum, library, Zoo</td>
<td>26</td>
<td>0</td>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>Bank</td>
<td>17</td>
<td>2</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Hotel</td>
<td>14</td>
<td>3</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Private medical practice/ dental practice</td>
<td>12</td>
<td>2</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>Public shelter, addiction center</td>
<td>10</td>
<td>0</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Shopping mall</td>
<td>7</td>
<td>1</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Store</td>
<td>6</td>
<td>0</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Police station/fire department</td>
<td>5</td>
<td>1</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td>4</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Church</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Train station</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Marina, harbor</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>
Abbreviations: AED, automated external defibrillator.

* Distribution of AEDs registered with the Danish AED network in Copenhagen, by December 31, 2011.

† High-risk areas were defined as grid cells with ≥1 cardiac arrest every 2 years.

‡ Low-risk areas were defined as grid cells with ≥1 cardiac arrest that did not fulfill criteria for high-risk areas.

§ Areas with no cardiac arrests were defined as grid cells without any cardiac arrests during the study period.
Figure I online-only Data Supplement. AED Dissemination and Prospective Coverage of Cardiac Arrests (2007–2011)

- In high-risk areas (p<0.0001, n=94)
- In all areas (p<0.0001, n=474)
- In low-risk areas (p<0.0001, n=380)

% of all cardiac arrests covered by AED

Year of cardiac arrest

2007  2008  2009  2010  2011
Legend: AED dissemination and coverage of prospective cardiac arrests (2007–2011) are shown for high-risk areas, low-risk areas, and all areas with cardiac arrests, in Copenhagen, Denmark. On the basis of locations of cardiac arrests during 1994–2011, high-risk areas were defined as areas with ≥1 cardiac arrest every 2 years. Low-risk areas were defined as areas with ≥1 cardiac arrest that did not fulfill the criteria for high-risk areas. Cardiac arrests were considered covered by an AED, if an AED had been deployed ≤ 100 m from the cardiac arrest location and prior to the cardiac arrest.