Optimizing public defibrillator deployment to overcome spatial and temporal accessibility barriers

[Final published article title: Overcoming Spatial and Temporal Barriers to Public Access Defibrillators Via Optimization]

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Version  Post-print/accepted manuscript

Additional publisher information  The final version of this article is available from Elsevier at https://doi.org/10.1016/j.jacc.2016.03.609

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Optimizing public defibrillator deployment to overcome spatial and temporal accessibility barriers

Short title: Optimizing spatiotemporal AED access

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Funding Sources:
Funded by the ZOLL Foundation (ZOLL Foundation Research Grant). The Resuscitation Outcomes Consortium Epiistry study is supported by a cooperative agreement (5U01 HL077863) with the National Heart, Lung, and Blood Institute in partnership with the National Institute of Neurological Disorders and Stroke, Canadian Institutes of Health Research–Institute of Circulatory and Respiratory Health, Defense Research and Development Canada, Heart and Stroke Foundation of Canada, and American Heart Association. Rescu Epistry is funded a centre grant from the Laerdal Foundation, and knowledge translation collaborative grants from Canadian Institutes of Health Research and the Heart and Stroke Foundation of Canada.

Disclosures:
None.

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Word Count: 4,929
Abstract

Background: Immediate access to an automated external defibrillator (AED) increases the chance of survival from out-of-hospital cardiac arrest (OHCA). Current deployment usually considers spatial AED access, assuming AEDs are available 24 hours a day.

Objectives: We sought to develop an optimization model for AED deployment, accounting for spatial and temporal accessibility, to evaluate if OHCA coverage would improve compared to deployment based on spatial accessibility alone.

Methods: This was a retrospective population-based cohort study using data from the Toronto Regional RescuNET cardiac arrest database. We identified all non-traumatic public-location OHCA in Toronto, Canada (01/2006–08/2014) and obtained a list of registered AEDs (03/2015) from Toronto emergency medical services. We quantified coverage loss due to limited temporal access by comparing the number of OHCA that occurred within 100m of a registered AED (“assumed 24/7 coverage”) with the number that occurred both within 100m of a registered AED and when the AED was available (“actual coverage”). We then developed a spatiotemporal optimization model that determines AED locations to maximize OHCA actual coverage and overcome the reported coverage loss. We computed the coverage gain between the spatiotemporal model and a spatial-only model on using 10-fold cross-validation. Statistical analyses were conducted using $\chi^2$ and McNemar’s tests.

Results: We identified 2440 atraumatic public OHCA and 737 registered AED locations. A total of 451 OHCA were covered by registered AEDs under assumed 24/7 coverage, and 354 OHCA under actual coverage, representing a coverage loss of 21.5% (P<0.001); daytime-8.6%, evening-28.6%, night-48.4%. Using the spatiotemporal model to optimize AED deployment, a 25.3% relative increase in actual coverage was achieved over the spatial-only approach (P<0.001); daytime-10.9%, evening-38.0%, and night-122.5%.
Conclusions: One in five OHCAs occurred near an inaccessible AED at the time of the OHCA. Potential AED use was significantly improved with a spatiotemporal optimization model guiding deployment.

Key words: Resuscitation, cardiac arrest, public access defibrillation, automated external defibrillator
Abbreviations:
Out-of-hospital cardiac arrest (OHCA)
Automated external defibrillator (AED)
Cardiopulmonary resuscitation (CPR)
Public access defibrillation (PAD)
Emergency Medical Service (EMS)
Resuscitation Outcomes Consortium (ROC)
Introduction:

Out-of-hospital cardiac arrest (OHCA) is a significant public health issue, associated with 450,000 deaths annually in North America and a less than ten percent survival rate.(1,2) Automated external defibrillator (AED) use, coupled with cardiopulmonary resuscitation (CPR), has been shown to increase survival from public-location cardiac arrest.(3-6)

Despite the substantial amount of financial resources committed to public access defibrillation (PAD) programs, AED usage in public-location OHCA cases remains low.(7-9) There are many potential barriers to bystander AED use including legal liability, awareness, training, technological limitations, and psychological factors.(10-12) Another major barrier is the limited availability of AEDs due to building access.(11,13-15)

The majority of the research in and guidelines for AED deployment focus on spatial factors with respect to cardiac arrest risk and AED availability. Studies have evaluated cardiac arrest risk by location type,(5,16-23) or optimized the deployment of AEDs geographically,(24,25) without considering temporal factors. In fact, the well-known American Heart Association guidelines for AED placement have suggested placing an AED where there has been a cardiac arrest every 2 years and, more recently, “in public locations where there is a relatively high likelihood of witnessed cardiac arrest”.(26,27) The European Resuscitation Council guidelines are similar.(28) AED deployment approaches that only consider spatial factors implicitly assume that AEDs and public locations housing AEDs are available and accessible 24 hours a day.

Although it is well-known that cardiac arrest incidence and survival vary substantially by time of day and day of week,(29,30) temporal access has largely been ignored in the literature, with one notable exception.(13) In this paper, we present the first mathematical optimization approach for AED deployment that considers both spatial and temporal accessibility. We hypothesize that OHCA coverage by existing AEDs is significantly overestimated when temporal accessibility is not considered,
and (2) optimizing the deployment of prospective AEDs, accounting for both spatial and temporal accessibility, can reverse the coverage loss and generate a statistically significant increase in OHCA coverage over an approach that only considers spatial accessibility.

**Methods:**

**Study Setting**

Toronto has a population of approximately 2.8 million people and has an area of approximately 630.18km². A single Emergency Medical Service (EMS) primarily serves the city, however neighboring EMS services respond to emergency events if they are close in proximity. Multiple EMS units and the fire department often respond to a single emergency event as Toronto has a tiered response system.

**Study Design and Patient Data**

This was a retrospective population-based cohort study using data from the Toronto Regional RescuNET cardiac arrest database; Rescu Epistry is compliant with the Resuscitation Outcomes Consortium (ROC) Epistry-Cardiac Arrest and based on the Strategies for Post Arrest Care methodologies described elsewhere.(31,32) All public-location, atraumatic OHCA episodes in the City of Toronto from January 2006–August 2014 were included in the study. Information for each OHCA entry includes demographic characteristics, circumstance of arrest, characteristics of care, and survival outcomes. Public locations included public buildings, places of recreation, industrial facilities, and outdoor public spaces, and excluded hospitals and nursing homes.

**Data Sources**

*Registered AEDs*
A list of registered AEDs was obtained from Toronto EMS as of March 2015. AED registration in Toronto is voluntary, but strongly encouraged. The AED data set contained 912 publicly and privately owned (included with owner consent) AEDs, located at 737 unique addresses. Each entry included the address and location type. Most entries included the hours of operations. Missing information was completed by online search, phone, or in-person visit (Section 1.1, Supplementary Appendix).

Candidate AED locations

A dataset of candidate locations for AED placement was collected from June 2014–January 2015, comprising 4898 businesses and public points of interest. For each location, we obtained the address and, if available, hours of operation. Data collection was carried out online, by phone, or by in-person visit.

Analyses

Analysis 1: Coverage loss of registered AEDs factoring in temporal availability

We first calculated assumed 24/7 coverage: an OHCA is considered covered if it occurred within 100 m\(^2\) of an AED regardless of the AED’s availability. Second, we calculated actual coverage: an OHCA is considered covered if it occurred both within 100 m of an AED and when the AED was available based on the location’s hours of operation. Locations were considered temporally inaccessible outside of their hours of operation. We chose a coverage radius of 100 m based on an estimate of the maximum round-trip distance a bystander can transport an AED within three minutes\(^2\) (33). Finally, we calculated relative coverage loss: assumed 24/7 coverage minus actual coverage all divided by assumed 24/7 coverage. Coverage loss was further analyzed by different times of day (daytime: 8:00AM–3:59PM, evening: 4:00PM–11:59PM, night: 12:00AM–7:59AM), days of the week (weekdays, weekends), geographic areas (downtown(34), outside downtown), and specific location types. We computed a 95%
confidence interval for the relative coverage loss using a paired proportions approach plus an error
propagation step to convert absolute to relative coverage loss(35,36). We also used a $\chi^2$ test to test for
statistically significant differences in coverage loss when compared across disjoint and unpaired
categories (time of day, geography, and day of week) of OHCAs, with a two-tailed value of $P < 0.05$ being
significant.

**Analysis 2: Coverage gain of AED locations from a spatiotemporal optimization model**

We developed a novel spatiotemporal optimization model for AED placement by augmenting a
previous spatial-only optimization model developed by our group(25) to account for temporal
information of both OHCA cases and candidate AED locations (see Section 1.2, Supplementary Appendix
for additional model details). Employing a user-defined number of locations ($N$), our model chooses the
best locations to place AEDs to maximize OHCA actual coverage by examining historical OHCA data.

The spatiotemporal model and spatial-only model were evaluated on the improvement of actual
coverage above a baseline of the actual coverage provided by the existing registered AED network in the
city. We used 10-fold cross-validation to compare the theoretical performance of the spatiotemporal
model and spatial-only model in terms of actual coverage on historical OHCA data as follows. The OHCAs
that were not already covered by the registered AEDs were randomly divided into 10 disjoint sets of
equal sizes, which served as the testing sets for each fold. In each fold, the remaining 90% of the OHCAs
comprised the training set. Note that in each fold, the training and testing sets are completely disjoint.
Additionally, the testing sets are disjoint across the folds (i.e., out-of-sample). The training set was used
as input to the optimization models to determine the $N$ optimal AED locations. The actual coverage of
the selected AED locations was assessed using the testing set OHCAs and then summed over the 10
folds. The totals over the 10 folds are reported the analysis. By using the testing set OHCAs for the final
evaluation of actual coverage, our reported results are out-of-sample. The optimization models were run for each fold for \( N = 50, 100, \ldots, 400 \).

For each \( N \), we calculated relative coverage gain: actual coverage from spatiotemporal model minus actual coverage from spatial-only model all divided by actual coverage from spatial-only model. Overall coverage gain was calculated as the weighted mean of the coverage gain for each \( N \), weighted by the actual coverage values from the spatial-only model. We computed 95% confidence intervals for the overall coverage gain and the coverage gain split by time of day, geography and day of week(37). Significance in the actual coverage differences was determined using McNemar’s test for each \( N \) with a two-tailed value of \( P<0.05 \) being considered significant.

Results:

Characteristics of cardiac arrest episodes

A total of 25,707 non-traumatic OHCAs occurred in Toronto from January 2006–August 2014. Of these, 2440 cases occurred in a public setting (Table 1). Of the 25,707 OHCAs, 942 (3.7%) survived to discharge, and of these, 361 occurred in a public setting, corresponding to a survival rate among public OHCAs of 14.8%. Differences in rates of witnessed by bystander (\( P<0.001 \)), received bystander CPR (\( P=0.001 \)), shockable (\( P<0.001 \)), and survival (\( P=0.04 \)) were significant (\( \chi^2 \) test) across the three times of day, but not the difference in bystander applied AED (\( P=0.17 \)). Table 2 shows the breakdown of the 2440 included public OHCAs by time of day, day of week and geography. The majority of all OHCAs occurred during the evening, night, and weekends (61.0%). Table 3 shows identical breakdowns for bystander applied AED. The difference in bystander applied AED between outside downtown during weekends (6.2%) and downtown during weekdays (11.2%) was statistically significant (\( P=0.01 \)).
Registered AED Data

Of the 737 AED locations, 542 (73.5%) were not open 24 hours a day and 211 (28.6%) were closed on weekends. Figure 1 shows the proportion of time that registered AEDs are available by time of day and day of week.

Analysis 1: Coverage loss of registered AEDs factoring in temporal availability

Coverage loss: overall, by time of day, by day of week, and by geography

Table 4 summarizes the coverage loss statistics. Out of the 2440 included OHCAs, 451 were covered under assumed 24/7 coverage while 354 were covered under actual coverage, resulting in a relative coverage loss of 21.5% (95% CI, 16.9%-26.1%). Coverage loss during the evening, night, and weekends was 31.6%, which is when the majority of all OHCAs occurred (Table 2).

Comparable coverage losses were observed in downtown during weekdays (17.2%), downtown during weekends (19.1%), and outside downtown during weekdays (19.0%). In comparison, the coverage loss was more than double outside downtown during weekends (38.8%); these differences were significant (P=0.04).

Coverage loss: location type

Table 5 summarizes the coverage loss experienced by registered AEDs categorized by their respective location types. Among location types with the most deployed AEDs, the largest coverage losses were observed at schools (39.7%), industrial facilities (39.3%), recreation/sports facilities (37.1%), offices (35.7%). These four location types account for 63.9% of AED locations. Transportation facilities experienced no coverage loss while having the largest number of covered OHCAs.

Analysis 2: Coverage gain of AED locations from a spatiotemporal optimization model
After the 354 OHCAAs covered by the registered AEDs were removed, 2086 remained for the 10-fold cross-validation optimization analysis.

The overall coverage gain (percent gain in actual coverage) from AED locations determined by the spatiotemporal model over the spatial-only model was 25.3% (95% CI, 22.9%-27.6%) (Figure 2). As shown in Figure 3, the overall coverage gain was statistically significant for all N (P<0.002 for all N). The Supplementary Appendix breaks down the results from Figure 2 for all N by time of day, day of week, and geography (Figures A1 to A7).

An equivalent interpretation of the 25.3% overall coverage gain is that the spatiotemporal model required 32.3% fewer AEDs than the spatial-only model to cover the same number of OHCAAs (Section 2.2., Supplementary Appendix).

Discussion:

Main findings

The two primary, synergistic findings presented in this paper were: 1) a significant proportion of OHCAAs occur close to a public AED that is inaccessible at the time of the arrest; 2) a mathematical model that explicitly accounts for both spatial and temporal accessibility when proposing prospective public AED locations has the potential to significantly increase the likelihood of having an accessible AED nearby during an OHCA event.

Analysis 1: Registered AEDs

A significant loss in OHCA coverage by public AEDs due to limited temporal access was observed across all times of day. The largest loss occurred at night, corresponding to the time period with the lowest percentage of OHCA cases that are witnessed by a bystander, receive bystander CPR/AED, and
survive to discharge. Although coverage loss was significantly different across the three times of day, the proportion of cases that received bystander AED was not. It is possible that nighttime OHCAs occur closer to an available AED or that responding bystanders at night are more willing to apply an AED. The latter possibility highlights the potential for improving survival further by improving AED accessibility at night.

We further examined our results by geography (downtown/not downtown) and day of week (weekday/weekend). We noted a significant difference in bystander applied AED between outside downtown during weekends and downtown during weekdays (Table 3). So, when considering the subgroups of day of week and geography, the highest bystander applied AED proportion coincided with the lowest coverage loss (downtown during weekdays), while the lowest bystander applied AED proportion coincided with the highest coverage loss (outside downtown during weekends). These results suggest a potential correlation between AED availability and usage.

Additionally, we observed that the coverage loss in downtown Toronto was similar during weekdays and weekends, unlike the coverage loss outside downtown, which was much greater on weekends. This observation suggests that temporal AED accessibility does not decrease as much during the weekend in downtown as it does outside downtown. Forty years ago, the city adopted a planning principle focused on balancing residential and commercial development in downtown.(38) The doubling of the downtown population since the mid-1970s has likely played a role in encouraging downtown businesses serving local residents to maintain robust opening hours, mitigating the weekend coverage loss.

A recent study examined coverage loss due to temporal AED accessibility in Copenhagen, Denmark.(13) Both studies noted a significant coverage loss overall: 33.5% in Copenhagen and 21.5% in Toronto. Regarding the difference, only 9.1% of AED locations in Copenhagen were open 24 hours a day versus 26.5% in Toronto. Certain location types had similar coverage losses including schools (39.7% in
Toronto vs. 40.8% in Copenhagen) and transportation facilities (no coverage loss in either). Offices had a larger coverage loss in Copenhagen than Toronto, whereas sports/recreation facilities had a smaller coverage loss. A possible explanation for this inversion is a difference in lifestyle and culture: according to an OECD work-life balance index, Denmark ranked first out of 36 while Canada ranked 24th.(39) Since Toronto and Copenhagen have similar OHCA risk at sports/recreation facilities(16,21), the difference in coverage loss may be partially explained by comparatively longer opening hours for offices and shorter opening hours for sports/recreation facilities in Toronto. Overall, these two studies suggest that coverage loss due to temporal factors is likely a universal problem, though it may vary by location type within a city and from city to city for the same location type.

Analysis 2: Optimization

Our spatiotemporal model represents one possible method to combat the effects of limited temporal accessibility without compromising spatial access when optimizing AED locations. The overall coverage gain demonstrated by our spatiotemporal model when locating prospective AEDs almost exactly offsets the coverage loss experienced by the existing registered AED network. Moreover, the coverage gain remained steady as more AEDs were placed (Figure 3), which suggests that the improvement in OHCA coverage is sustainable as the AED network grows, and is not due to the addition of more AEDs but rather due to the accounting for temporal accessibility. The greatest coverage gain occurred at night, which is also the time of day when Toronto’s existing AED network experienced the greatest loss and when survival was lowest.

Recall that the spatiotemporal model’s 25.3% coverage gain, holding the number of AED locations constant, was equivalent to a 32.3% decrease in the number of AED locations required to achieve the same coverage as its spatial-only counterpart. This equivalence provides two different ways to measure of the value of temporal information when optimizing AED locations: in terms of improved
potential for AED use given constant system resources, or lower cost of system implementation/upkeep for the same coverage level. A similar “trade-off curve” between number of deployed AEDs and AED radius was previously observed.(24)

The spatiotemporal model can be used as a decision-support tool for stakeholders involved in the strategic placement of public AEDs such as Emergency Medical Services, urban planning departments, or foundations that fund public AEDs. Evaluating AED deployment policies, such as blanket coverage of certain location types, can easily be done. A user may vary the number of prospective AED locations considered (e.g., based on a funding limit) to examine the potential impact on OHCA coverage. Because the model considers both existing AED locations and future AED placements simultaneously, potential redundancies or holes in coverage can be minimized. The model can also be used as an assistive tool for AED relocation by ignoring the existing AEDs when identifying optimal AED locations. While the model uses city-specific information as inputs, it is a general model and translatable to any city. Its practical applicability elsewhere will depend on data availability in the target city. Furthermore, the model is suitable for both small scale (e.g., neighborhoods, university campuses) as well as large scale (e.g., city-wide) deployments. Additional applications could include integration with assistive technologies such as mobile apps or software pertaining to AED placement.

Limitations

A tacit assumption is that the historical distribution of OHCAs is representative of the future. Some justification has been provided in the literature already(40) and a recent study in progress provides additional evidence for Toronto that the distribution is stable over time.(41) Additionally, we demonstrated that our spatiotemporal model provides coverage gain even with variability in OHCA occurrences, which was captured via out-of-sample disjoint testing sets in the 10-fold cross-validation.
AED registration is voluntary in the city of Toronto. It is likely that our list of registered AEDs does not include all AEDs in the city. However, we believe this to be a minor limitation in our analysis since it is unlikely a bystander would be able to find and use an unregistered AED in an emergency. Most unregistered AEDs are privately owned and sometimes solely for internal use, and would not be relevant in this study. Also, our numerical results focus on the change in coverage, not the magnitude of coverage, so missing AEDs would likely have a minimal impact.

Coverage provides a convenient quantitative measure for analysis, but ultimately does not equal survival. While coverage and survival are likely positively correlated, coverage is a proxy for usage at best. There has been some effort to relate coverage to AED usage and survival(42) but additional study is required. Coverage gains due to spatiotemporal optimization, all else being equal, should eventually translate to an increased likelihood of an AED being found and applied in the future.

We used hours of operation to measure temporal availability, but there are other contributing factors to availability that are not captured in hours of operation. For example, employee breaks and tardiness may reduce AED accessibility. Additionally, opening hours may vary slightly by season and in our analysis we used a single snapshot of the hours to represent availability throughout the year.

Our coverage definition does not include the effects of multiple AEDs placed in one location or the advantages of closer proximity to the AED within 100 m. The latter issue has been addressed in another study. (42)Note that AED use and coverage may be higher in these cases as bystanders may be able to locate an AED more rapidly. Doors, walls, and multiple floors were not explicitly modeled. Our spatiotemporal model outputs specific locations for prospective AED deployment primarily for the purpose of pinpointing temporally compromised OHCA hotspots that may be addressed with AEDs in nearby, temporally advantaged locations. The model should not be seen as a prescriptive approach to determining specific buildings in which AEDs should be placed because factors like security, presence of a trained response team, signage, and hours of operation should all be considered in actual deployment
decisions. In cities where AED placement decisions are decentralized and most of the suitable locations are private, addressing temporally compromised OHCA hotspots identified by the model will require substantial public-private partnership.

Accessibility is only one piece of the larger puzzle in optimizing public defibrillator use and bystander response in an emergency. For example, bystander witness likelihood limits survival improvement through AED use. Other barriers were noted in the Introduction. There are many synergistic and recent efforts to improve awareness, wayfinding, and EMS integration.(43,44)

Conclusion

Temporal accessibility of public AEDs is critical to both the measurement of true OHCA coverage and the decision on where to locate AEDs. The likelihood of a nearby AED being inaccessible during an OHCA was significant: one in five OHCA occurred near an inaccessible AED. Fortunately, our computational results show that a significant increase in accessibility is possible if temporal information is properly integrated in AED location decisions. In Toronto, the coverage gain from spatiotemporal optimization was largest at night, which was when the largest loss was experienced by the existing AED network and when survival was lowest. In other words, the potential for spatiotemporal optimization to reverse the effects of limited temporal accessibility was greatest precisely when the need is also greatest. While strategic AED placement has numerous benefits(11,16,45), these benefits cannot be fully captured without the inclusion of temporal information in the placement decision, a consideration that has generally been missing in previous studies and guidelines. Current evaluation methods may be incorrectly assessing and, thus, significantly overestimating OHCA coverage. A change is needed in the way AED placement guidelines are currently designed, specifically to include temporal information.
Perspectives

Competency in Medical Knowledge 1: Temporal accessibility of public AEDs is important for the measurement of true OHCA coverage. The likelihood of a nearby AED being inaccessible during an OHCA was significant (one in five OHCAs).

Competency in Medical Knowledge 2: A significant increase in accessibility is possible if temporal information is properly integrated in AED location decisions. Spatiotemporal optimization of AED placements has the potential to reverse the effects of limited temporal accessibility on OHCA coverage.

Translational Outlook 1: While coverage and survival (and/or bystander AED use) are likely positively correlated, further investigation will lead to a better understanding on how coverage can serve as a proxy for survival and AED use.

Translational Outlook 2: Additional factors besides accessibility contribute to defining ideal buildings/locations for effective AED placement and should be examined to help improve AED programs.

Acknowledgments

The authors acknowledge the helpful feedback given by audience members at the American Heart Association Scientific Sessions 2015 on an early presentation of this research. We are grateful to Cathy Zhan for help with gathering demographic data associated with the cardiac arrest. The local Epistry data set is derived from source documentation provided by Toronto Regional EMS and Fire services participating in the Resuscitation Outcomes Consortium clinical trials.
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Figures

Figure 1. Registered AED availability. AED availability by time of day.
Overall coverage gain was calculated as the weighted mean of the coverage gain for each $N$, weighted by the actual coverage values of the spatial-only model.
Figure 3. Comparing spatiotemporal and spatial-only model OHCA coverage. Actual coverage of testing set OHCA by prospective AED locations determined by the spatiotemporal and spatial-only models. The difference in actual coverage was statistically significant for all N (McNemar, P<0.002).
<table>
<thead>
<tr>
<th>Characteristic*</th>
<th>Daytime</th>
<th>Evening</th>
<th>Night</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(8:00AM - 3:59PM)</td>
<td>(4:00PM - 11:59PM)</td>
<td>(12:00AM - 7:59AM)</td>
</tr>
<tr>
<td>Total</td>
<td>(n=2440)</td>
<td>(n=1252)</td>
<td>(n=348)</td>
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<td>Average age ±SD</td>
<td>59.0±17.5</td>
<td>60.3±17.9</td>
<td>58.9±16.8</td>
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<tr>
<td>Male</td>
<td>58.9±16.7</td>
<td>60.1±17.2</td>
<td>58.7±16.1</td>
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<td>Female</td>
<td>59.4±20.6</td>
<td>61.1±21.0</td>
<td>60.3±19.5</td>
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<td>Male sex, n (%)</td>
<td>1979 (81.1)</td>
<td>1021 (81.5)</td>
<td>686 (81.7)</td>
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<tr>
<td>Witnessed by bystander, n (%)</td>
<td>1142 (46.8)</td>
<td>590 (47.1)</td>
<td>446 (53.1)</td>
</tr>
<tr>
<td>Received bystander CPR, n (%)</td>
<td>1019 (41.8)</td>
<td>533 (42.6)</td>
<td>371 (44.2)</td>
</tr>
<tr>
<td>Bystander applied AED, n (%)</td>
<td>191 (7.8)</td>
<td>96 (7.7)</td>
<td>75 (8.9)</td>
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<tr>
<td>Ambulance response interval, median (IQR), minutes</td>
<td>5.88 (2.68)</td>
<td>5.75 (2.60)</td>
<td>5.82 (2.62)</td>
</tr>
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<table>
<thead>
<tr>
<th>Initial cardiac rhythm, n (%)</th>
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<tr>
<td>Shockable&lt;sup&gt;+&lt;/sup&gt;</td>
</tr>
<tr>
<td>Not Shockable&lt;sup&gt;+&lt;/sup&gt;</td>
</tr>
<tr>
<td>Survival to discharge, n (%)</td>
</tr>
</tbody>
</table>

SD, standard deviation; AED, automated external defibrillator; CPR, cardiopulmonary resuscitation; and IQR, interquartile range

*Number missing from total: age (79), sex (2), witnessed by bystander (18), received bystander CPR (2), bystander applied AED (46), arrival interval (2), initial cardiac rhythm (68), survival (26)

<sup>+</sup> Shockable includes, ventricular fibrillation, ventricular tachycardia and patients listed as shockable. Not shockable includes asystole, pulseless electrical activity, patients listed as not shockable, and patients whose initial rhythm was not obtained as resuscitation was stopped before rhythm analysis by protocol due to obvious signs of death.
Table 2. Public OHCAs by time of day, day of week, and geography.

<table>
<thead>
<tr>
<th>Time of Day</th>
<th>Downtown Weekday</th>
<th>Outside Weekday</th>
<th>Downtown Weekend</th>
<th>Outside Weekend</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daytime (8:00AM - 3:59PM)</td>
<td>173 (7.1)</td>
<td>778 (31.9)</td>
<td>57 (2.3)</td>
<td>244 (10.0)</td>
<td>1252 (51.3)</td>
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<tr>
<td>Evening (4:00PM - 11:59PM)</td>
<td>111 (4.5)</td>
<td>480 (19.7)</td>
<td>46 (1.9)</td>
<td>203 (8.3)</td>
<td>840 (34.4)</td>
</tr>
<tr>
<td>Night (12:00AM - 7:59AM)</td>
<td>54 (2.2)</td>
<td>182 (7.5)</td>
<td>28 (1.1)</td>
<td>84 (3.4)</td>
<td>348 (14.3)</td>
</tr>
<tr>
<td>Total</td>
<td>338 (13.9)</td>
<td>1440 (59.0)</td>
<td>131 (5.4)</td>
<td>531 (21.8)</td>
<td>2440 (100.0)</td>
</tr>
</tbody>
</table>

Table 3. Bystander applied AED use on public OHCAs by time of day, day of week, and geography.

<table>
<thead>
<tr>
<th>Time of Day</th>
<th>Downtown Weekday</th>
<th>Outside Weekday</th>
<th>Downtown Weekend</th>
<th>Outside Weekend</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daytime (8:00AM - 3:59PM)</td>
<td>24 (13.9)</td>
<td>51 (6.6)</td>
<td>6 (10.5)</td>
<td>15 (6.1)</td>
<td>96 (7.7)</td>
</tr>
<tr>
<td>Evening (4:00PM - 11:59PM)</td>
<td>10(9.0)</td>
<td>43 (9.0)</td>
<td>5 (10.9)</td>
<td>17 (8.4)</td>
<td>75 (8.9)</td>
</tr>
<tr>
<td>Night (12:00AM - 7:59AM)</td>
<td>4 (7.4)</td>
<td>12 (6.6)</td>
<td>3 (10.7)</td>
<td>1 (1.2)</td>
<td>20 (5.7)</td>
</tr>
<tr>
<td>Total</td>
<td>38 (11.2)</td>
<td>106 (7.4)</td>
<td>14 (10.7)</td>
<td>33 (6.2)</td>
<td>191 (7.8)</td>
</tr>
</tbody>
</table>
Table 4. OHCA coverage loss of registered AEDs by time of day, day of week, and geography.

<table>
<thead>
<tr>
<th>OHCAs covered</th>
<th>Daytime (8:00AM - 3:59PM)</th>
<th>Evening (4:00PM - 11:59PM)</th>
<th>Night (12:00AM - 7:59AM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total (n=2440)</td>
<td>Assumed 24/7 coverage</td>
<td>451</td>
<td>221</td>
</tr>
<tr>
<td></td>
<td>Actual coverage</td>
<td>354</td>
<td>202</td>
</tr>
<tr>
<td></td>
<td>Coverage loss (%)</td>
<td>21.5</td>
<td>8.6</td>
</tr>
<tr>
<td>Weekdays (n=1778)</td>
<td>Assumed 24/7 coverage</td>
<td>342</td>
<td>176</td>
</tr>
<tr>
<td></td>
<td>Actual coverage</td>
<td>279</td>
<td>166</td>
</tr>
<tr>
<td></td>
<td>Coverage loss (%)</td>
<td>18.4</td>
<td>5.7</td>
</tr>
<tr>
<td>Weekends (n=662)</td>
<td>Assumed 24/7 coverage</td>
<td>109</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>Actual coverage</td>
<td>75</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>Coverage loss (%)</td>
<td>31.2</td>
<td>20.0</td>
</tr>
<tr>
<td>Downtown (n=469)</td>
<td>Assumed 24/7 coverage</td>
<td>158</td>
<td>74</td>
</tr>
<tr>
<td></td>
<td>Actual coverage</td>
<td>130</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>Coverage loss (%)</td>
<td>17.7</td>
<td>9.5</td>
</tr>
<tr>
<td>Outside (n=1971)</td>
<td>Assumed 24/7 coverage</td>
<td>293</td>
<td>147</td>
</tr>
<tr>
<td></td>
<td>Actual coverage</td>
<td>224</td>
<td>135</td>
</tr>
<tr>
<td></td>
<td>Coverage loss (%)</td>
<td>23.6</td>
<td>8.2</td>
</tr>
<tr>
<td>Weekday</td>
<td>Assumed 24/7 coverage</td>
<td>116</td>
<td>57</td>
</tr>
<tr>
<td>Outside</td>
<td>Assumed 24/7 coverage</td>
<td>226</td>
<td>119</td>
</tr>
</tbody>
</table>
The differences between coverage loss during daytime, evening, and night were significant (P<0.001). The differences remained significant when considering only weekdays (P<0.001), downtown (P=0.04), and outside downtown (P<0.001), but not weekends (P=0.22). The difference in coverage loss between weekdays (18.4%) and weekends (31.2%) was significant (P=0.04), but not between downtown (17.7%) and outside downtown (23.6%) (P=0.30).

<table>
<thead>
<tr>
<th>Downtown (n=1440)</th>
<th>Actual coverage</th>
<th>183</th>
<th>113</th>
<th>58</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coverage loss (%)</td>
<td>19.0</td>
<td>5.0</td>
<td>29.3</td>
<td>52.0</td>
</tr>
<tr>
<td>Weekend</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Downtown (n=131)</td>
<td>Assumed 24/7 coverage</td>
<td>42</td>
<td>17</td>
<td>19</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Actual coverage</td>
<td>34</td>
<td>14</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Coverage loss (%)</td>
<td>19.1</td>
<td>17.7</td>
<td>21.1</td>
<td>16.7</td>
</tr>
<tr>
<td>Outside (n=531)</td>
<td>Assumed 24/7 coverage</td>
<td>67</td>
<td>28</td>
<td>27</td>
<td>12</td>
</tr>
<tr>
<td>Downtown</td>
<td>Actual coverage</td>
<td>41</td>
<td>22</td>
<td>15</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Coverage loss (%)</td>
<td>38.8</td>
<td>21.4</td>
<td>44.4</td>
<td>66.7</td>
</tr>
<tr>
<td>Location Type</td>
<td>Number of locations with an AED, n (%)</td>
<td>OHCAs covered</td>
<td>Coverage loss (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------</td>
<td>---------------------------------------</td>
<td>---------------</td>
<td>------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Assumed 24/7 coverage, N</td>
<td>Actual coverage, n</td>
<td></td>
<td></td>
</tr>
<tr>
<td>School</td>
<td>190 (25.8)</td>
<td>68</td>
<td>41</td>
<td>39.7</td>
<td></td>
</tr>
<tr>
<td>Recreation/sports facility</td>
<td>165 (22.4)</td>
<td>89</td>
<td>56</td>
<td>37.1</td>
<td></td>
</tr>
<tr>
<td>Transportation facility</td>
<td>93 (12.6)</td>
<td>144</td>
<td>144</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Industrial facility</td>
<td>62 (8.4)</td>
<td>28</td>
<td>17</td>
<td>39.3</td>
<td></td>
</tr>
<tr>
<td>Office</td>
<td>54 (7.3)</td>
<td>56</td>
<td>36</td>
<td>35.7</td>
<td></td>
</tr>
<tr>
<td>Outdoor seasonal facility</td>
<td>39 (5.3)</td>
<td>8</td>
<td>6</td>
<td>25.0</td>
<td></td>
</tr>
<tr>
<td>Law enforcement agency</td>
<td>33 (4.5)</td>
<td>56</td>
<td>39</td>
<td>30.4</td>
<td></td>
</tr>
<tr>
<td>Library</td>
<td>25 (3.4)</td>
<td>20</td>
<td>14</td>
<td>30.0</td>
<td></td>
</tr>
<tr>
<td>Office building</td>
<td>16 (2.2)</td>
<td>43</td>
<td>37</td>
<td>14.0</td>
<td></td>
</tr>
<tr>
<td>Medical facility</td>
<td>15 (2.0)</td>
<td>11</td>
<td>9</td>
<td>18.2</td>
<td></td>
</tr>
<tr>
<td>Residences - condominium</td>
<td>13 (1.8)</td>
<td>3</td>
<td>3</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Emergency services</td>
<td>9 (1.2)</td>
<td>0</td>
<td>0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Residence - long term care or homeless shelters</td>
<td>6 (0.8)</td>
<td>14</td>
<td>14</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Church</td>
<td>4 (0.5)</td>
<td>1</td>
<td>0</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>Community hall</td>
<td>4 (0.5)</td>
<td>2</td>
<td>2</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Convention facility</td>
<td>3 (0.4)</td>
<td>4</td>
<td>4</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Entertainment facility</td>
<td>2 (0.3)</td>
<td>2</td>
<td>1</td>
<td>50.0</td>
<td></td>
</tr>
<tr>
<td>Shopping centre</td>
<td>2 (0.3)</td>
<td>5</td>
<td>2</td>
<td>60.0</td>
<td></td>
</tr>
<tr>
<td>Hotel</td>
<td>1 (0.1)</td>
<td>1</td>
<td>1</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Zoo</td>
<td>1 (0.1)</td>
<td>0</td>
<td>0</td>
<td>0.0</td>
<td></td>
</tr>
</tbody>
</table>