HHS Public Access
Author manuscript
Resuscitation. Author manuscript; available in PMC 2018 May 24.

Published in final edited form as:
Resuscitation. 2016 December ; 109: 9–15. doi:10.1016/j.resuscitation.2016.09.021.

Characteristics of automated external defibrillator coverage in Philadelphia, PA, based on land use and estimated risk

Benjamin W. Chrisinger[a,*], **Anne V. Grossestreuer**[b], **Meredith C. Laguna**[c], **Heather M. Griffis**[d,f], **Charles C. Branas**[e], **Douglas J. Wiebe**[e], and **Raina M. Merchant**[d,f]

[a]Stanford Prevention Research Center, Stanford University School of Medicine, 1070 Arastradero Road, Suite 300, Palo Alto, CA 94304, USA

[b]Department of Emergency Medicine, Beth Israel Deaconess Medical Center, Boston, MA, USA

[c]Department of Pediatrics, University of California, San Francisco, CA, USA

[d]Department of Emergency Medicine, Hospital of the University of Pennsylvania, Philadelphia, PA, USA

[e]Department of Biostatistics and Epidemiology, Perelman School of Medicine, University of Pennsylvania, Philadelphia, PA, USA

[f]Penn Medicine Social Media and Health Innovation Lab, Philadelphia, PA, USA

Abstract

Aim—Approximately 424,000 out-of-hospital cardiac arrests (OHCA) occur in the US annually. As automated external defibrillators (AED) are an important part of the community response to OHCA, we investigated how well the spatial demand (likelihood of OHCA) was met by the spatial supply (AEDs) in a dense urban environment.

Methods—Using geographic information system (GIS) software, we applied kernel density and optimized hot spot procedures with two differently-sized radii to model OHCA incidence rates from existing studies, providing an estimate of OHCA likelihood at a given location. We compared these density maps to existing AED coverage in the study area. Descriptive statistics summarized coverage by land use.

Results—With a 420-ft buffer, we found that 56.0% (79.9%, 840-ft buffer) of the land area in the city center was covered by existing AEDs at, though 70.1 (91.5)% of the OHCA risk was covered using kernel density and 79.8% (98.1) was covered using hot spot analysis.

Conclusions—The difference in coverage by area and risk seems to indicate efficient placement of existing AEDs. Our findings also highlight the possible benefits to expanding the influence of AEDs by lowering search times, and identify opportunities to improve AED coverage in the study

*Corresponding author: Fax: +1 650 723 6450. chrisinger@stanford.edu (B.W. Chrisinger).

Conflict of interest statement
The authors have no conflicts of interest to report.

Disclosures
No financial disclosures were reported by the authors of this paper.

area. This article offers one method by which local officials can use spatial data to prioritize attention for AED placement and coverage.

Keywords

Automated external defibrillator; Cardiac arrest; Geographic information systems; Land use

Introduction

Sudden cardiac arrest is a major health problem in the United States (US), with approximately 424,000 arrests occurring outside of the hospital annually.[1] An estimated 16–20% of these out-of-hospital cardiac arrests (OHCAs) occur in a public place,[2–4] representing approximately 68,000–85,000 arrests that could be potentially influenced by publicly available and accessible automated external defibrillators (AEDs). Quick response to cardiac arrests is crucial, as the longer the brain and heart are deprived of oxygen, the more damage occurs. For every minute treatment is delayed, survival is decreased by 7–10%.[5] However, there is little guidance for AED placement that would provide optimal geographic access, described here as coverage, for possible or likely cardiac arrests. This study introduces one such tool for considering the placement of AEDs in dense urban areas: estimating OHCA risk based on land use to empirically achieve better AED coverage.

Existing research finds that both population and environmental variables can help identify areas of higher OHCA risk in dense urban areas and rural settings.[6–9] Folke et al. mapped the locations of OHCAs in Copenhagen, Denmark and examined whether demographic variables such as age, education, and income could predict locations of cardiac arrest.[10] These variables successfully predicted areas that were likely to have one arrest event every 5 years, which is the American Heart Association (AHA)-recommended threshold for AED placement.[10,11] Brooks et al. examined the rate of OHCAs over a four-year period in Toronto, Canada, calculated average annual per-site cardiac arrest incidence by location type, and compared it to AED coverage of that location type, in effect identifying “high-risk” locations as well as “high-coverage” locations.[12] They found that hotels/motels and hostels/shelters were likely to have OHCA but were less-covered by AEDs; while schools were lower risk for arrest but more likely to be covered by AEDs.[12] The study also detailed how some locations, such as race tracks and casinos, annually saw high large numbers of OCHA events, though there were far fewer of these sites citywide (only three sites) compared to other land uses (e.g., nearly 12,500 retail stores).[12] Other work from Toronto mapped OHCAs in public locations against registered AEDs and determined that if AEDs were in place at all of the top 30 arrest locations, an additional 112 arrests would have been covered, suggesting that modeling to prioritize AED locations should be considered in PAD programs,[13] especially when employed in location types that see higher rates of OHCA per site.

Taken together, these studies support a data-driven approach to AED deployment, though the current AED coverage ecosystem in many localities (absent a coordinated system) is not well understood. Especially in dense urban areas, it is possible that AEDs are almost always somewhere nearby; yet, whether or not these devices are strategically located in high-risk or high-access areas remains to be seen.

Spatial dimensions of AED need

Within the fields of planning and geographic science, much conceptual groundwork has focused on the siting of community facilities, including fire and rescue services, trauma centers, and parks, providing the basis for spatially understanding resource distribution and optimization, raising important questions of efficiency, equity, cost, and effectiveness.[14–16] Given that the potentially life-saving effects of AEDs can only be realized if AEDs themselves are located close to OHCA events, there is an inherently spatial dimension to their optimal siting, in line with previous resource allocation studies. Furthermore, certain types of locations and facilities are more likely sites for OHCA, underlining an additional dimension pertaining to land use.

Local governments in most American cities provide current land use maps to illustrate classifications of activities and buildings that occur on a given parcel, which are typically regulated by local zoning policies. Land use maps are the cornerstone for comprehensive planning processes, and serve as a resource for numerous city agencies, private developers, and citizens' groups. Within Philadelphia, PA, the land use map is a freely accessible, recognizable public resource[17] that offers a means of characterizing types of activities and facilities where OHCA are likely to occur. By comparing these data to actual AED locations in the study area, land use designations provide a framework to consider the spatial contexts of AED coverage.

Study purpose

The aim of this study was to spatially evaluate the land use characteristics of where AEDs are currently located, estimate which parts of our study area have the highest risk of OHCA, and determine how well the current AED landscape covers this risk.

Methods

Site identification

Given that sites are unequally likely to see a cardiac arrest, we adopted a system of weighting and differentiation from prior work by Brooks et al. as a way to classify each location across the landscape of our geographic study area to represent the likelihood for an OHCA to occur.[12] The study by Brooks et al. presents location-based incidence of OHCA, based on records from the Canadian Resuscitation Outcomes Consortium Epistry—Cardiac Arrest, and AED presence in Toronto, based on the Toronto Emergency Medical Services registry of AEDs. Government agencies in Philadelphia do not readily collect or provide these types of data; in lieu of these records, we used ratios generated by Brooks et al. as a land use-based weighting scheme to estimate these data in our study area. A separate study identified locations of actual AEDs in Philadelphia (described further below), which provided an opportunity to help validate this estimation, at least for the presence of AEDs. Using the downtown region of Philadelphia as the study area and data sources described in

Table 1, locations including schools, shopping malls, museums, pools, and recreation centers were geocoded in ArcGIS 10.1 and classified using one of three methods.[18]

First, using an official city land use map, we identified closely matching land use designations.[17] The land use map provides spatial information about citywide land use by parcels, which were converted to centroid points. Sixteen of the 24 sites from prior work by Brooks et al. were able to be matched using the city's land use data; unmatched sites were addressed using the following two methods.[12] Second, for four of the eight sites described by Brooks et al. which could not be matched to the land use map (post-secondary and trade schools, primary and secondary schools, public pools, and transit terminals, available as point shapefiles), the Pennsylvania Geospatial Data Clearinghouse (PASDA) for available location data was investigated.[12,19] Third, for the four uses (community recreation centers, convention centers, hostel/shelters, and large shopping malls) which could not be matched to either the land use map or other available data, Google searches were conducted for locations within our study area. Site addresses were geocoded using an address locator built with a Philadelphia street network file.

Coverage of actual AED locations

Previous research in Philadelphia had attempted to locate all AEDs through door-to-door surveying, though significant social, logistical, and ethical hurdles limited the comprehensiveness of this endeavor.[20] In response, a 2012 crowdsourcing initiative, the "MyHeartMap Challenge," had participants find and validate the location of AEDs locations in the city. The resulting AED database from MyHeartMap was geocoded in this study using the same address locator.[18] Of 295 AEDs reported in the study area, 249 were automatically matched with the address locator, 32 were matched by manually placing points, and 14 were manually matched to recognized addresses. Sites with multiple AEDs – most often high-rise buildings with devices on multiple floors – were only represented by a single point to estimate ground-level access. Two buffers, one of 420 ft and another of 840 ft, estimated as an approximately 1.5 and 3.0 min walking distance, respectively, to give a range for hypothetical defibrillation response times (3 min and 6 min) following an OHCA event.[21,22]

Site weighting and density

To account for the differences in likelihood of OHCA events between site types, each site was assigned weights according to ratios described in Brooks et al. and listed in Table 1.[12] These weights were then used in an ArcGIS kernel density procedure. Kernel density a method for simultaneously considering how important each individual point is, achieved by weighting points, and how close one point is to other points; taken together, these considerations create a density surface (see Fig. 1). We used the aforementioned 420 and 840-ft radii to approximate the spheres of influence around sites.

To ensure that variations between and within the relatively short city blocks (approximately 400–500 ft in downtown Philadelphia[23]) within our downtown study area were detected, 30 ft by 30 ft grid cells were used for the kernel density procedure. With this process, we generated a mapped surface layer of downtown Philadelphia such that the value at each point (latitude–longitude coordinate) represented an kernel density-based estimate that an OHCA could occur at that location, relative to the particular land use at the point and others in the immediate vicinity. Density values from these grid cells were extracted and classified as "covered" or "uncovered" by both three and six-minute walking radii from known AEDs locations in the study area. The raster surfaces were also joined to the original land use map, appending land use characteristics to existing cell-level fields.

Another technique to spatially consider OHCA risk employs the same weighting strategy based on Brooks et al., but identifies significant clusters of points, or "hot spots," with a Getis-Ord G_i* procedure in ArcMap 10.1.[18,24] While the kernel density procedure creates a surface of OHCA risk that can be sampled, the optimized hot spot analysis identifies which of the input points (in our case, the OHCA-weighted locations that appear in the study area), are significantly clustered at or above a 90% confidence interval. Essentially, this identifies locations are not only higher-risk, but also located near other sites with similarly elevated chances of OHCA incidence. Similar to our approach with kernel density, we classified these points as covered or uncovered by the three and six minute walking radii from known AEDs.

Analysis

Descriptive statistics were used to compare actual AED coverage across land use types and of the two likelihood raster surfaces. We used the 20 most prevalent land uses (excluding classifications of "water" and roads/sidewalks) to summarize our findings, describing over 90% of the study area. The GIS procedures detailed above used all available land use classifications (see Appendix A for definitions). Six residential land use categories were collapsed into a single group due to this study's focus on the potential for OHCA events in public spaces. Original and revised analyses were performed in 2014 and 2016, respectively.

Results

Our analysis considered 33 types of sites: 24 were included in the analysis and nine excluded, based on presence within the study area. In this section, we first describe the extent of spatial coverage in the study area by land use type, measured by accessible area to known AEDs. Next, we report the coverage surface overlap with areas weighted by the likelihood of OHCA events. Table 2 presents the prevalence and coverage findings for each of these twenty land uses; a general summary follows below.

Land use characteristics

The prevalence of land use types ranges from 1.1% (commercial food service and drinking) to 20.2% (residential) of the study area. Top land use types (by area) in the study area include residential, commercial office (11.9%), parking (9.4%), park/open-space (6.7%) and commercial store or office with apartments.

AED coverage of different land uses

Existing AEDs covered approximately 56.0% of the land area in our study area by 3-min response radii, and 79.9% by 6-min response radii. By area, the most-covered land uses within the 3-min radii included courts of law, commercial services, and commercial offices (all nearly 85% and above); for 6-min radii, courts, commercial services and commercial offices were the most covered (all greater than 96%). Among the least-covered areas by 3-min radii were vacant parcels, warehousing and distribution and park/open spaces (all less than 29%); for 6-min radii, vacant parcels, warehousing and distribution and amusement were the least covered (all less than 59%).

AED coverage of estimated OHCA event likelihood

Using the kernel density measure of OHCA likelihood, 70.1% of total risk was covered by known AEDs within a 3-min response distance and 91.5% covered within a 6-min response distance. Using 3-min radii, courts of law were by far the most-covered land use, followed by commercial food service and drinking, cultural and natural history, and commercial stores and educational sites (all nearly 85% and above); for 6-min radii, courts (100.0%), commercial food service and drinking, commercial services, and cultural and natural history were the most covered (all 98% and above). The least-covered land uses under the 3-min radius assumption include active recreation, warehousing and distribution and other public open spaces (all less than 20%); using 6-min radii, warehousing and distribution, transportation rail right-of-way yards and stations, and active recreation were the least covered (all less than 70%).

Results from the optimized hotspot analysis are slightly more optimistic. At the 3-min distance, 79.8% of locations that are significantly clustered were covered by known AEDs (CI = 90%, 95%, or 99%); at a radius of 6-min, 98.1% of significant locations were covered. Of the uncovered significant locations, most were parking lots (14 sites), commercial stores or offices with apartments (8 sites), or hotel/motels (7 sites).

Discussion

Some programs for public access defibrillation (PAD) have been evaluated, such as one in city-owned buildings, airports, golf courses and pools in Los Angeles, California, which found that airports were the most common site of cardiac arrest where an AED was used (71% of all AED usage), but arrests also occurred in other public spaces.[25] PAD programs involve identifying places where cardiac arrests are likely to happen, where bystanders are likely to use an AED, and where there is a suitable accessible location where to place an AED.[26] Despite this, only limited requirements or recommendation for AED placement exist in the US, and the choices to purchase an AED, service and maintain it, and determine who may access it are largely left to individuals. For instance, in Philadelphia, state laws only require AED placement in health clubs and recommend placement in schools.[27] Additionally, PAD programs are considered to be most cost-effective when coverage is driven by assessments of OHCA risk.[28]

While AED coverage by land area is less than comprehensive in our study area, overall risk for OHCA is fairly covered by both of our estimates (kernel density and hot spot). Regardless of risk estimation or radius used, these coverage figures are at least ten percent higher than the raw land area measure (see Table 3). This shows that even without a system for coordinating the locations of defibrillators within the study area, the devices were nonetheless achieving somewhat efficient coverage. To some extent this illustrates the more adequate coverage of high-need sites; essentially, many areas with high OHCA risk, though not the most prevalent geographically, have fairly good access to AEDs. Furthermore, our study is consistent with other research finding that moderate expansions to the distance assumed for AED influence can achieve large gains in risk coverage, raising both methodological and practical questions.[29]

Setting priorities for AED coverage

The analysis presented here offers a means of prioritizing the attention of public health officials with regard to AED coverage. Based on estimates of where OHCA events might occur, we identify both geographic areas and land uses that could merit further investigation. Visual representations of access and need (such as Fig. 1) can possibly inform future advocacy for more publicly accessible and available devices in different localities. Geographic priority areas may be further explored through partnerships with local organizations or institutions, incorporating neighborhood knowledge to properly identify both risks and viable candidate sites for AED placement. Land use priority areas may be an arena for local policymaking, possibly mandating AED availability in certain types of facilities or areas. Our findings also highlight the possible benefits to expanding the influence of AEDs by lowering search times, and identify opportunities to improve AED coverage in the study area.

Limitations

We used existing data from Brooks et al.,[12] and assume that OHCA incidence to be similar between Toronto and Philadelphia. An improved and more accurate risk model could be calibrated with local OHCA event data. Similarly, there is an implicit assumption that the land uses described in previous work are roughly equivalent to the uses we identified through a variety of data sources. Further analyses incorporating actual OHCA locations are needed to validate these estimations, and determine if there are actual hazards associated with these uncovered sites. An additional assumption is made regarding vertical space, which limits the area of coverage, given that an OHCA may take place on a level higher than the ground floor of a building.

By constructing buffers around known AEDs, areas of coverage were estimated. The size and location of remaining coverage gaps is highly dependent on the distance of influence beyond a device that is assumed, though these models also suggest that a large gain in risk coverage can be achieved by expanding these buffers. In practice, the distances that make up true AED coverage are complex, and depend on a variety of personal (knowledge, speed, etc.) and environmental factors (visibility, accessibility, etc.). For instance, Leung et al. identified significant challenges in locating existing AEDs via a door-to-door surveying program in Philadelphia, noting that most (88%) of buildings did not have AEDs, but of those which did, many building employees were reluctant to allow surveyors to see the AED, suggesting possible barriers to easy access in an emergency.[20] Additionally, the most successful PAD programs located AEDs where there were likely to be trained personnel with a professional duty to respond, such as casino workers or airline personnel, which points to the importance of other site-specific characteristics not measured by this study.[30] Nevertheless, if these barriers could be lowered, such as by requiring that devices be in highly-visible and accessible locations, it is reasonable to believe that larger buffers of AED influence are warranted.

Prior work has identified that locating actual AEDs can be challenging, though as public health officials seek to understand the dynamics of spatial coverage, some understanding of the status quo is needed.[20] Additional research is also needed to understand the differences and similarities in OHCA incidence between different geographies, especially urban settings where PAD programs are most plausible. Should the Toronto-based estimates of location-based incidence hold true in Philadelphia, other researchers could contribute cross-validations in other dense urban locations using their own data. The method outlined here, while driven by several necessary assumptions, is replicable in other locations that have similar land use data available to researchers.

Conclusions

The current deployment of AEDs in our downtown Philadelphia study area provides coverage of 56% of land area and about 70–80% of cardiac arrest risk (based on site incidence reported in Toronto) using a 3-min response radius and 80% of land area and about 92–98% of OHCA risk using a 6-min radius. The difference in coverage by area and risk appears to indicate relatively efficient placement of existing AEDs absent a coordinated citywide system, with some opportunities for improvement depending on the assumed ideal response time.

Acknowledgments

The authors would like to acknowledge the contributions of Nancy Ting, DVM, to this study, and the helpful feedback from our anonymous reviewers. The corresponding author was supported by a National Science Foundation Graduate Research Fellowship and National Institutes of Health Institutional National Research Service Award during parts of the analysis and manuscript preparation.

References

1. Go AS, Mozaffarian D, Roger VL, et al. Heart disease and stroke statistics—2014 update: a report from the American Heart Association. Circulation. 2014; 129:e28–92. http://dx.doi.org/10.1161/01.cir.0000441139.02102.80. [PubMed: 24352519]
2. Weisfeldt ML, Everson-Stewart S, Sitlani C, et al. Ventricular tachyarrhythmias after cardiac arrest in public versus at home. N Engl J Med. 2011; 364:313–21. http://dx.doi.org/10.1056/NEJMoa1010663. [PubMed: 21268723]
3. Becker L, Eisenberg M, Fahrenbruch C, Cobb L. Public locations of cardiac arrest. Circulation. 1998; 97:2106–9. http://dx.doi.org/10.1161/01.CIR.97.21.2106. [PubMed: 9626169]
4. Investigators TPADT. Public-access defibrillation and survival after out-of-hospital cardiac arrest. N Engl J Med. 2004; 351:637–46. http://dx.doi.org/10.1056/NEJMoa040566. [PubMed: 15306665]
5. Weisfeldt ML, Sitlani CM, Ornato JP, et al. Survival after application of automatic external defibrillators before arrival of the emergency medical system: evaluation in the resuscitation outcomes consortium population of 21 million. J Am Coll Cardiol. 2010; 55:1713–20. http://dx.doi.org/10.1016/j.jacc.2009.11.077. [PubMed: 20394876]
6. Griffis HM, Band RA, Ruther M, et al. Employment and residential characteristics in relation to automated external defibrillator locations. Am Heart J. 2016; 172:185–91. http://dx.doi.org/10.1016/j.ahj.2015.09.022. [PubMed: 26856232]
7. Ong MEH, Tan EH, Yan X, et al. An observational study describing the geographic-time distribution of cardiac arrests in Singapore: what is the utility of geographic information systems for planning

public access defibrillation? (PADS phase I) Resuscitation. 2008; 76:388–96. http://dx.doi.org/10.1016/j.resuscitation.2007.09.006. [PubMed: 17976889]

8. Portner ME, Pollack ML, Schirk SK, Schlenker MK. Out-of-hospital cardiac arrest locations in a rural community: where should we place AEDs? Prehosp Disaster Med. 2004; 19:352–5. http://dx.doi.org/10.1017/S1049023X00001977. [PubMed: 15645630]
9. Mears G, Mann NC, Wright D, Schnyder ME, Dean JM. Validation of a predictive model for automated external defibrillator placement in rural America. Prehosp Emerg Care. 2006; 10:186–93. http://dx.doi.org/10.1080/10903120500541241. [PubMed: 16531375]
10. Folke F, Gislason GH, Lippert FK, et al. Differences between out-of-hospital cardiac arrest in residential and public locations and implications for public-access defibrillation. Circulation. 2010; 122:623–30. http://dx.doi.org/10.1161/CIRCULATIONAHA.109.924423. [PubMed: 20660807]
11. The American Heart Association in Collaboration with the International Liaison Committee on Resuscitation. Guidelines 2000 for cardiopulmonary resuscitation and emergency cardiovascular care. Part 4: the automated external defibrillator: key link in the chain of survival. Circulation. 2000; 102:I60–76. [PubMed: 10966663]
12. Brooks SC, Hsu JH, Tang SK, Jeyakumar R, Chan TCY. Determining risk for out-of-hospital cardiac arrest by location type in a Canadian urban setting to guide future public access defibrillator placement. Ann Emerg Med. 2013; 61:530–8. http://dx.doi.org/10.1016/j.annemergmed.2012.10.037, e2. [PubMed: 23522611]
13. Chan TCY, Li H, Lebovic G, et al. Identifying locations for public access defibrillators using mathematical optimization. Circulation. 2013; 127:1801–9. http://dx.doi.org/10.1161/CIRCULATIONAHA.113.001953. [PubMed: 23553657]
14. ReVelle C. Siting ambulances and fire companies: new tools for planners. J Am Plann Assoc. 1991; 57:471–84. http://dx.doi.org/10.1080/01944369108975521.
15. Branas C, ReVelle C. TRAMAH to the rescue: new theoretical resource allocation model has practical, potentially lifesaving applications. MS TODAY. 1999; 26:38–41.
16. Talen E. The spatial logic of parks. J Urban Des. 2010; 15:473–91. http://dx.doi.org/10.1080/13574809.2010.502335.
17. Philadelphia city. [accessed 21.07.16] Philadelphia—land use, full metadata. Pennsylvania spatial data access. 2013. http://www.pasda.psu.edu/uci/FullMetadataDisplay.aspx?file=PhiladelphiaLandUse201309.xml
18. ESRI. ArcMap 10.0. Redlands, CA: ESRI; 2010.
19. [accessed 21.07.16] Pennsylvania spatial data access. http://www.pasda.psu.edu/
20. Leung AC, Asch DA, Lozada KN, et al. Where are lifesaving automated external defibrillators located and how hard is it to find them in a large urban city? Resuscitation. 2013; 84:910–4. http://dx.doi.org/10.1016/j.resuscitation.2013.01.010. [PubMed: 23357702]
21. Browning, RC., Baker, EA., Herron, JA., Kram, R. Effects of obesity and sex on the energetic cost and preferred speed of walking. J Appl Physiol. 2005. http://dx.doi.org/10.1152/japplphysiol.00767.2005
22. De Maio VJ, Stiell IG, Wells GA, Spaite DW. Optimal defibrillation response intervals for maximum out-of-hospital cardiac arrest survival rates. Ann Emerg Med. 2003; 42:242–50. http://dx.doi.org/10.1067/mem.2003.266. [PubMed: 12883512]
23. Budick, S. [accessed 21.07.16] What makes a city walkable?. PlanPhilly. 2008. http://planphilly.com/articles/2008/07/23/3568
24. Manepalli, URR., Bham, GH., Kandada, S. [accessed 02.08.16] Evaluation of hot-spots identification using kernel density estimation and Getis-ord on I-630. 2011. https://trid.trb.org/view.aspx?id=1286977
25. Eckstein M. The Los Angeles public access defibrillator (PAD) program: ten years after. Resuscitation. 2012; 83:1411–2. http://dx.doi.org/10.1016/j.resuscitation.2012.03.029. [PubMed: 22484436]
26. Davies CS, Colquhoun M, Graham S, Evans T, Chamberlain D. Defibrillators in public places: the introduction of a national scheme for public access defibrillation in England. Resuscitation. 2002; 52:13–21. http://dx.doi.org/10.1016/S0300-9572(01)00439-7. [PubMed: 11801344]

27. [accessed 24.07.16] National conference of state legislatures state laws on cardiac arrest and defibrillators. 2012. http://www.ncsl.org/research/health/laws-on-cardiac-arrest-and-defibrillators-aeds.aspx. Published January 31, 2012

28. Folke F, Lippert FK, Nielsen SL, et al. Location of cardiac arrest in a city center. Circulation. 2009; 120:510–7. http://dx.doi.org/10.1161/CIRCULATIONAHA.108.843755. [PubMed: 19635969]

29. Siddiq AA, Brooks SC, Chan TCY. Modeling the impact of public access defibrillator range on public location cardiac arrest coverage. Resuscitation. 2013; 84:904–9. http://dx.doi.org/10.1016/j.resuscitation.2012.11.019. [PubMed: 23201501]

30. Gilchrist, S., Schieb, L., Mukhtar, Q., Valderrama, A., Yoon, P., Sasson, C. A summary of public access defibrillation laws, United States, 2010. Prev Chronic Dis. 2012. http://dx.doi.org/10.5888/pcd9.110196

31. The Philadelphia Code. City of Philadelphia: General Provisions, Zoning and Planning. Vol Bill No. 110845https://law.resource.org/pub/us/code/city/pa/Philadelphia/title14.pdf [accessed 2.08.16]

Appendix A. Definitions of land use classifications (adapted from The Philadelphia Code)

Classification	Definition
Residential	This category includes uses that provide living accommodations for one or more persons
Commercial office	This category includes uses in an enclosed building, customarily performed in an office, that focus on providing executive, management, administrative, government, professional, or medical services
Transportation parking	Parking that is not provided to comply with minimum off-street parking requirements and that is not provided exclusively to serve occupants of or visitors to a particular use, but rather is available to the public at-large. A parking facility that provides both accessory and nonaccessory parking shall be classified as non-accessory parking if it leases 25% or more of its spaces to non-occupants of or persons other than visitors to a particular use
Park open space	Recreational facilities associated with pastimes that are incidental to natural open space. These facilities require minor land development, require minimal maintenance, and have little impact on natural open space
Cultural & natural history	Museum-like preservation and exhibition of objects in one or more of the arts and sciences, gallery exhibition of works of art, or library collection of books, manuscripts, and similar materials for study and reading
Commercial store	This category includes uses involving the sale, lease, or rental of new or used goods to the ultimate consumer within an enclosed structure, unless otherwise specified
Education	Public and private schools at the primary, elementary, junior high, or high school level that provide basic education; colleges and other institutions of higher learning that offer courses of general or specialized study leading to a degree
Hotel motel	Uses that provide temporary lodging for fewer than 30 days where rents are charged by the day or by the week or portion thereof and may also provide food or entertainment primarily to visitors and tourists
Heath care	Uses providing medical or surgical care to patients and offering inpatient (overnight) care
Commercial service	Commercial Services includes uses that provide for consumer or business services, for the repair and maintenance of a wide variety of products, and for entertainment
Warehousing & distribution	This category includes uses that provide and distribute goods in large quantities, principally to retail sales, commercial services, or industrial establishments. Long-term and short-term storage of supplies, equipment, commercial goods, recyclable materials and personal items is included
Worship	Religious services involving public assembly that customarily occur in synagogues, temples, mosques, churches, and other facilities used for religious worship
Transport. rail ROW yards/ stations	Stations, off-street passenger waiting areas, and loading/unloading areas for local and regional transit service

Classification	Definition
Courts	Office uses related to the administration of local, state, or federal court services or functions
Other public open space	Undeveloped land left in a natural state for specific use as visual open space or environmental purposes
Active recreation	Recreational facilities that require major land development, structure construction, and a moderate- to high-level of maintenance and can accommodate large groups of people
Amusement	An establishment that offers to patrons four or more mechanical or electrical devices or games, such as pinball machines, ping pong, darts, shooting galleries or similar devices or games, excluding juke boxes and amusement devices in the establishments regulated by the Liquor Control Board of the Commonwealth and vending machines for the dispensing of goods
Commercial food service & drinking	Uses that prepare or serve food or beverages for on- or off-premise consumption. Establishments that meet the definition of a use classified in the eating and drinking establishments use subcategory and that also include occasional live entertainment may be classified as eating and drinking establishment uses, provided that any establishment that meets the definition of a nightclub and private club use must be classified and regulated as a nightclub and private club (See § 14-601(7)(c)(.3) (Nightclubs and Private Clubs))

Adapted from: The Philadelphia Code, Zoning & Planning.[31]

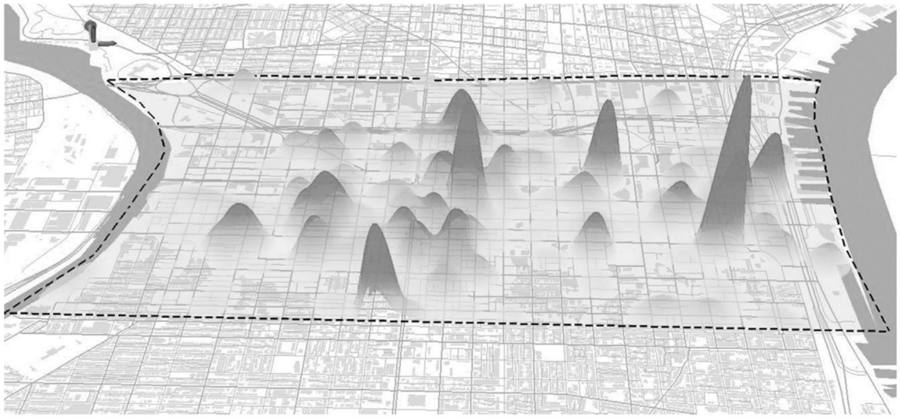

Fig. 1.

Higher peaks and darker shading in the study area (delineated by dashed line) indicate areas of greater OHCA likelihood at or nearby a specific point, according to the kernel density procedure described in the Methods.

Table 1

Summary of Philadelphia data sources and location-based weights according to Brooks et al.[12]

Sites[a]	Average annual OHCAs per site	AED count/total sites	Map layer(s)	Source[b]
Community recreation center	0.017	0.45	Community center, PPR recreation facilities	Google
Convention center	0.11	0.5	Convention center	Google
Gas/auto station	0.0022	0	Parcels with commercial—auto land use	LUM
Hostel/shelter	0.14	0.0408	Hostel/shelter	Google
Hotel/motel	0.15	0.0338	Hotel	LUM
Industrial	0.0018	0.011	Parcels with industrial land use	LUM
Jail	0.62	0.8	Correctional facility land use parcels	LUM
Large shopping malls	0.051	0.052	Shopping plaza	Google
Library	0.006	0.3	Parcels with library land use	LUM
Municipal buildings	0.0082	0.11	Parcels with courts or other civic land use	LUM
Museum	0.011	0.0476	Parcels with cultural or natural history land use	LUM
Office	0.0057	0.03364	Parcels with commercial—office land use	LUM
Parking lots	0.0029	0	Parcels w/transportation – parking or transportation – parking/commercial mix land use	LUM
Place of worship	0.0048	0.0146	Parcels with worship land use	LUM
Police, fire, ambulance facility/station	0.0069	0.21	Parcels with public safety land use	LUM
Post-secondary school/trade school	0.014	2.16	Post-secondary/trade schools	Google, PASDA
Primary school and secondary school	0.0038	1.05	Philadelphia school facilities	PASDA
Private club	0.0044	0.02	Parcels with fraternal/social club land use	LUM
Public pools	0.021	0.38	Public pools and spraygrounds	PASDA
Residence (university, religious)	0.011	1	Parcels with dormitory Land use	LUM
Retail store	0.002	0.0000801	Commercial retail	LUM
Sports field	0.035	0	Parcels with active recreation land use	LUM
Theater	0.0072	0.23	Parcels with performing arts land use	LUM
Transit terminals	0.087	0.0487	SEPTA HSR stations, SEPTA regional rail stations, bus terminals	PASDA

[a]Excluded: racetrack/casino, shopping centers, sports arena, truck station, golf course, fairground, other educational establishment, farm, zoo.

[b]Abbreviations: LUM, land use map; PASDA, Pennsylvania Spatial Data Access.

Table 2

Summary of spatial analyses by land use type.

Land use	LU prevalence % overall	% area covered 3-min (6-min)	% OHCA likelihood covered 3-min (6-min)
Residential	20.2%	35.1 (73.9)	49.3 (82.6)
Commercial office	11.9%	84.9 (96.5)	78.9 (98.1)
Transportation parking	9.4%	60.1 (84.6)	72.9 (90.9)
Park open space	6.7%	29.0 (69.9)	69.1 (95.0)
Commercial store or office with apts	6.3%	50.8 (75.9)	65.0 (87.9)
Cultural & natural history	6.3%	52.4 (65.8)	88.0 (98.4)
Commercial store	4.2%	72.6 (90.9)	85.3 (96.4)
Education	3.0%	83.9 (95.9)	84.7 (94.0)
Hotel motel	2.6%	82.5 (95.6)	78.6 (95.2)
Heath care	2.4%	69.6 (86.4)	79.4 (93.2)
Commercial service	2.2%	94.8 (99.0)	46.1 (98.7)
Vacant parcels	2.1%	21.3 (40.2)	53.4 (75.5)
Warehousing & distribution	2.0%	23.8 (40.9)	12.7 (42.3)
Worship	1.9%	61.3 (86.3)	48.8 (88.4)
Transport. rail ROW yards/stations	1.7%	39.0 (84.5)	35.2 (51.7)
Courts	1.4%	100.0 (100.0)	99.7 (100.0)
Other public open space	1.4%	29.0 (68.8)	19.2 (70.9)
Active recreation	1.3%	47.7 (87.8)	12.0 (69.4)
Amusement	1.3%	55.7 (58.7)	76.9 (98.1)
Commercial food service & drinking	1.1%	62.1 (77.8)	89.8 (98.9)

Table 3

Percent coverage by existing AEDs in study area by land area and estimates of OHCA risk (kernel density and hot spot).

	Buffer size	
	3-min (420 ft)	**6-min (840 ft)**
Land area	56.0	79.9
OHCA risk: kernel density	70.1	91.5
OHCA risk: hot spot	79.8	98.1