

Walking Route–Based Calculation is Recommended for Optimizing Deployment of Publicly Accessible Defibrillators in Urban Cities

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Background—A straight line–based model is often used to calculate the distance between an out-of-hospital cardiac arrest (OHCA) and the location of an automated external defibrillator (AED). This model may be inaccurate as it overlooks any obstacles between the OHCA and AED. This study aimed to elucidate the effect of the straight line–based and walking route–based calculation on the average distance between an historical OHCA and the closest AED and the coverage rate of AEDs, ie, the proportion of historical OHCA that were within 100 meters of an AED. It is hoped that the findings will help policy makers in deploying AEDs in optimal urban settings.

Methods and Results—This was an observational study conducted in Hong Kong. The average distance between an historical OHCA and its closest AED and the coverage rate of AEDs were calculated with both the straight line–based and walking route–based model. A total of 1637 AEDs and 5119 cases of OHCA were included for analysis. The average distances calculated by the straight line–based and walking route–based model were 230.8 and 545.3 meters, respectively. The coverage rate calculated by the straight line–based model was 30.04%, while that by the walking route–based model was 11.17%.

Conclusions—The straight line–based model may underestimate the average distances and overestimate the coverage rate in an urban setting. The walking route–based model may be more useful for studies of AED deployment in urban cities. (*J Am Heart Assoc.* 2020;9:e014398. DOI: 10.1161/JAHA.119.014398.)

Key Words: automated external defibrillator • sudden cardiac arrest • deployment

Public access defibrillation programs are useful to improve the survival rate of out-of-hospital cardiac arrest (OHCA).¹ One critical factor that leads to the success of such programs is shortened time to first defibrillation. In respect to this, existing guidelines recommend that an automated external defibrillator (AED) should be placed such that a bystander can get to it within 100 meters of a cardiac arrest.^{2–4} How to ensure that an AED is available within 100 meters of an OHCA has been a focus of investigations. Different mathematical models aimed at optimizing AED deployment have been developed and tested.^{5–9} These models have used either the average distance between an OHCA and its closest AED or coverage rate, ie, the proportion of historical OHCA that are

within 100 meters of an AED as a measure of whether AED deployment is optimal. One commonality of these models is that the calculation of the distance was based on a straight line radius distance on a map. However, in an urban setting, streets and alleys twist around buildings. A study by Bryan¹⁰ used a walking route–based calculation to optimize the AED locations. The OHCA and candidate AED locations in their study, however, lacked representativeness in terms of the OHCA they chose and the candidate locations for placing additional AEDs. The target samples of OHCA were extracted from ambulance calls, and only 48 calls were real OHCA. The candidate locations for placing the new AEDs were 212 restaurants. They did not consider other locations where OHCA more commonly occur, eg, sports grounds and transport stations. The present study aimed to elucidate the effect of the straight line– and walking route–based calculation on the average distance between an historical OHCA and the closest AED and the coverage rate of AEDs in an urban setting. The findings should bring more insight to policy makers when they are planning for AED deployment in their localities.

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Methods

All data and materials used in this study have been made publicly available and can be accessed at <https://github.com>

Clinical Perspective

What Is New?

- There could be significant differences in the average distance between an out-of-hospital cardiac arrest and the closest automated external defibrillator (AED) and the coverage rate of AED between the calculations by the straight line-based and walking route-based model.
- The straight line-based model tends to underestimate the average distance between an out-of-hospital cardiac arrest and the closest AED and overestimate the coverage rate of AEDs.

What Are the Clinical Implications?

- The walking route-based model is preferred to a straight line-based model in planning AED deployment in urban settings.

om/Caine/m/maxcovr. This was an observational study conducted in Hong Kong from July 1, 2015, to December 31, 2016. Hong Kong is a highly urbanized city with a population of 7.4 million and an area of 1100 square kilometers. The incidence of OHCA was estimated to be 72 cardiac arrests per 100 000 people.¹¹ There is no AED registry in Hong Kong. The use and placement of AEDs is unregulated and unguided. A public accessible defibrillator in this study was defined as an AED that was reachable by any person in the community. Sources of data of the publicly accessible AEDs in this study were the major AED suppliers in Hong Kong, government offices, the Leisure and Cultural Services Department (LCSD), the Department of Health, St. John Brigade, Hong Kong Red Cross, major mall owners, public utilities corporations such as the Mass Transit Railway, and the Heart-Safe School Project.¹² Each AED identified during the study period was recorded with an exact postal address. Data accuracy was ensured by door-to-door verification and direct contact with the individuals in charge of the premises or facilities where the AEDs were housed.

An historical cohort of nontrauma OHCA cases was used in the calculation of the average distance between an OHCA and its closest AED and the coverage rate. The data of the OHCA cases were from the database prospectively collected by the local emergency medical service, which is run by the Hong Kong Fire Services Department of the Hong Kong Government, from August 1, 2012, to July 31, 2013. In this database, the locations of cardiac arrests attended by the emergency medical service were recorded as longitude and latitude.

To facilitate quantification of the spatial relationship with the historical cases of OHCA, the addresses of the AEDs identified in the study period were first converted to longitude

Table 1. Distribution of Existing AEDs

Location	Frequency, No. (%)
Educational institutions	809 (49.4)
Recreational facilities	479 (29.3)
Mass transit railway stations	216 (13.2)
Malls and commercial buildings	74 (4.5)
Government buildings	56 (3.4)
Others	3 (0.2)

AEDs indicates automated external defibrillators.

and latitude by Python 2.7 with pygeocoder packages (Python Software Foundation) and Google's Geocoding API. These geographical information system data, together with those of OHCA, were then converted into Universal Transverse Mercator format. When the distances between points on a map are calculated, the Universal Transverse Mercator coordinate system allows the distances based on meters constantly rather than considering degrees and minutes. R for Windows 3.2.5 (package "rgdal," "raster," "rgeos," and "ggplot2") was used to perform the geographical information system analysis and visualization. To quantify the spatial relationship, 2 computations were then performed. First, the average distance between an OHCA with its closest AED was calculated. Second, the coverage rate was obtained by calculating the proportion of historical OHCA occurring within 100 meters of an AED. The straight line-based and walking route-based distances, which did not include elevation, were used in the calculation of these 2 measures. The straight line distances were calculated by Haversine formula. The walking route distances were calculated by the Open Source Routing Machine, which is designed as a routing engine for the shortest path in road networks.¹³ The back end was built on Ubuntu 19.04 x64 (Canonical Ltd.). Chi-square and *t* tests were used to verify the statistical difference where appropriate. The study was approved by the institutional review board of the University of Hong Kong/Hospital Authority Hong Kong West Cluster and informed consent was waived.

Table 2. Locations of Historical OHCA

Location	Frequency, No. (%)
Home	2654 (51.8)
Public places (excluding streets)	528 (10.3)
Streets	154 (3)
Residential care homes for the elderly	1564 (30.6)
En route to hospital	219 (4.3)

OHCA indicates out-of-hospital cardiac arrests.

Table 3. Spatial Relationship of Existing AED and OHCA

	Straight Line–Based Model	Walking Route–Based Model
OHCAs within 100 m of an AED, No.	1544	574
Coverage rate, %	30.04	11.17
Average distance, mean±SD, m	230.8±360.8	545.3±727.8

AED indicates automated external defibrillator; OHCA, out-of-hospital cardiac arrest.

Results

During the study period, 1637 AEDs were identified across all districts of Hong Kong. The number of AEDs per 10 000 population and per kilometer squared were 2.23 and 1.48, respectively. The majority (49.4%) of AEDs were installed at educational institutions. Deployment at recreational facilities came second (29.3%). These recreational facilities were mostly manned by the LCSD and included sports centers, parks, swimming pools, beaches, museums, and libraries (Table 1).

There were 5154 nontrauma OHCA cases from the database from August 1, 2012, to July 31, 2013. Thirty-five

cases were excluded because of wrong or absent geographical information system information. Therefore, 5119 cases were analyzed. The most common location was patients' home (51.8%). Approximately 13% of cardiac arrests occurred in public locations (including streets) (Table 2).

Table 3 shows the spatial relationship between the AED identified during the study period and the historical cases of OHCA. The results given by straight line–based and walking route–based calculation are different. If calculated by the walking route–based model, the coverage rate is one third of those calculated by the straight line–based model, while the average distance is more than double of the latter. Histograms of the straight line and walking route distances (Figure 1) and scatterplots of one distance versus the other, indicating the regions where either metric indicates being >100 meters from the nearest AED unit, are also given (Figure 2).

Discussion

Different geographic tools and mathematical models have been used to describe or optimize AED deployment. For example, hotspot plot can identify the locations with insufficient AEDs in a small space. A weakness of this kind of plot

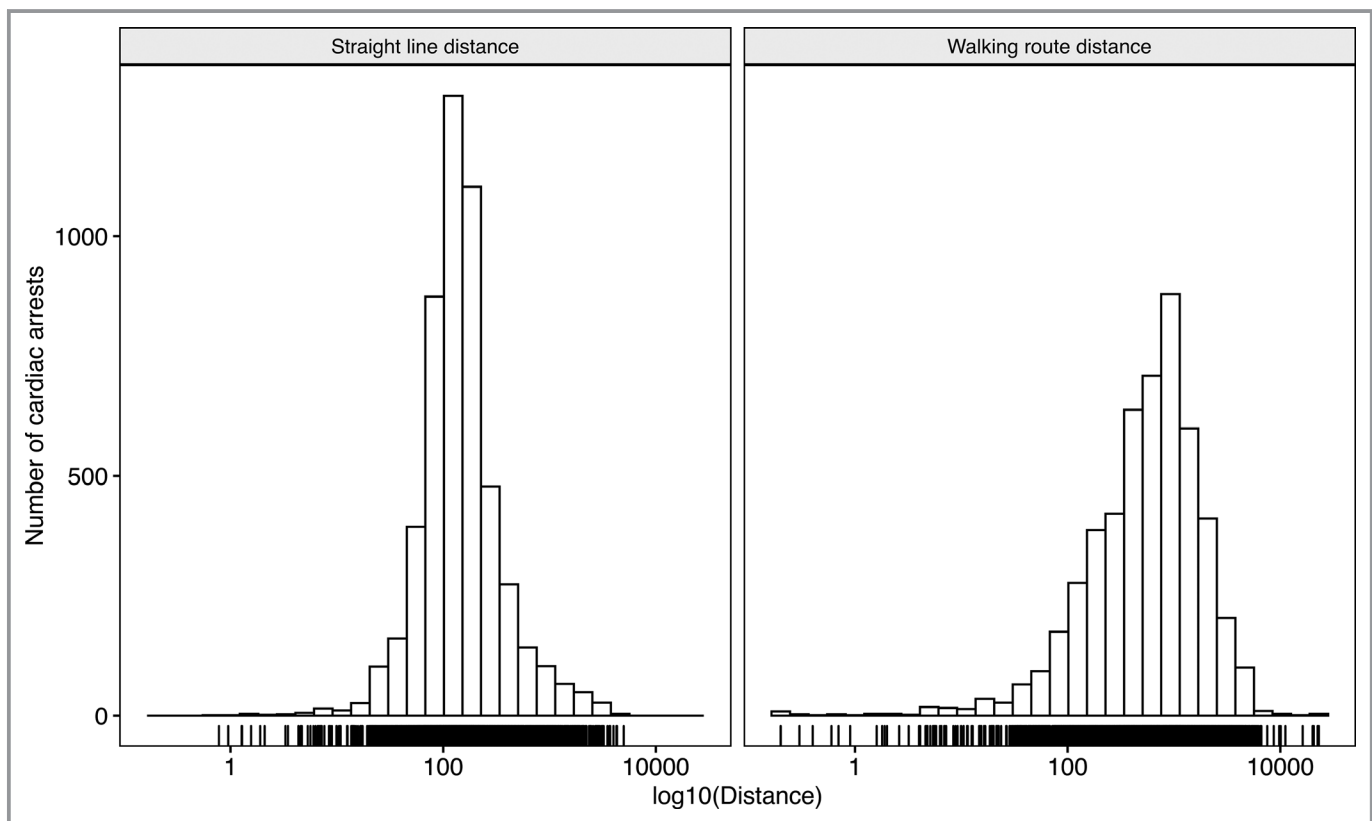


Figure 1. Histograms showing the distribution of the historical out-of-hospital cardiac arrests with reference to an automated external defibrillator as calculated by the straight line–based model (left) and walking route–based model (right).

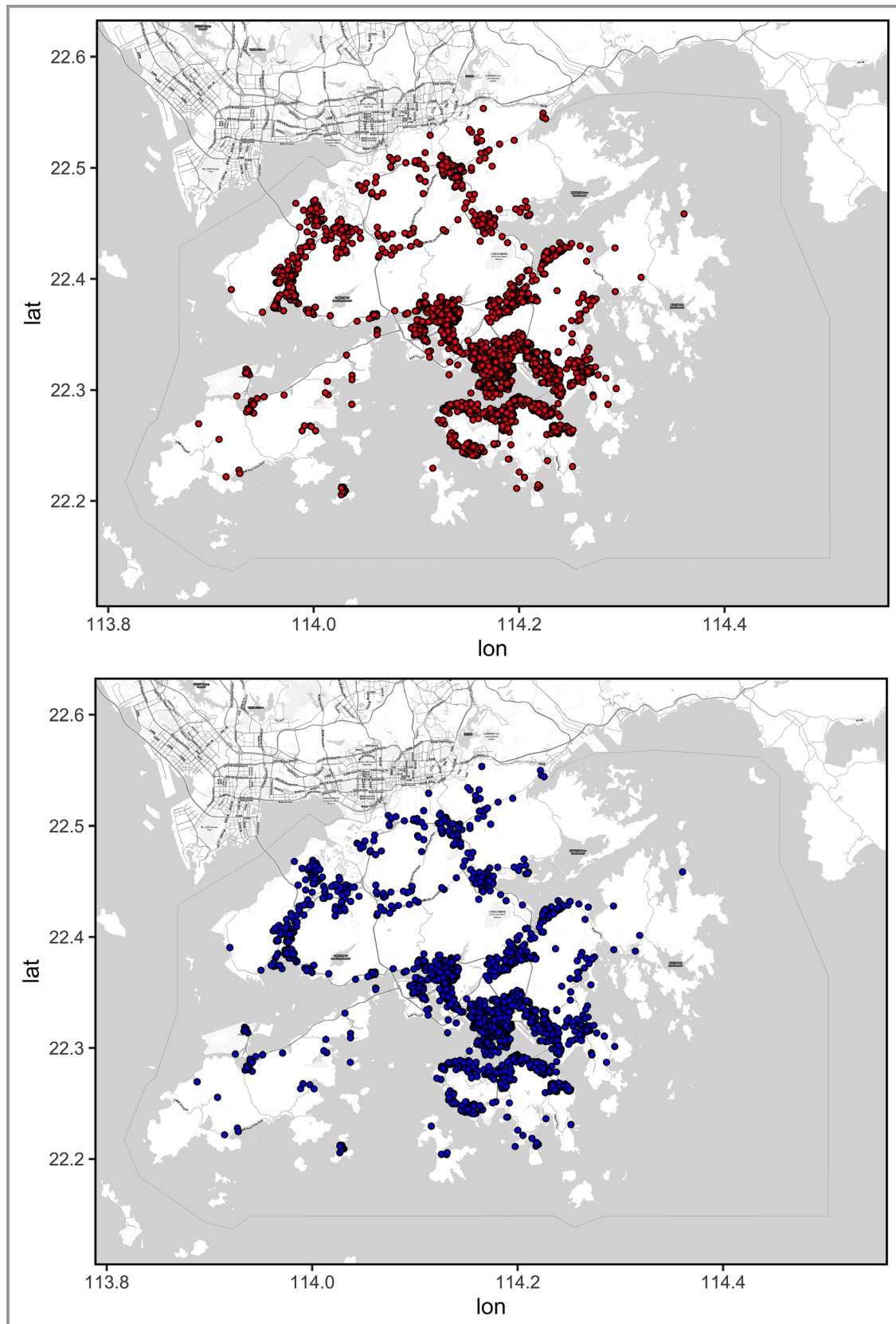


Figure 2. Scatterplots of one distance vs the other, indicating the regions where either metric indicates being >100 meters (upper: by straight line-based calculation; lower: by walking route-based calculation) from the nearest automated external defibrillator.

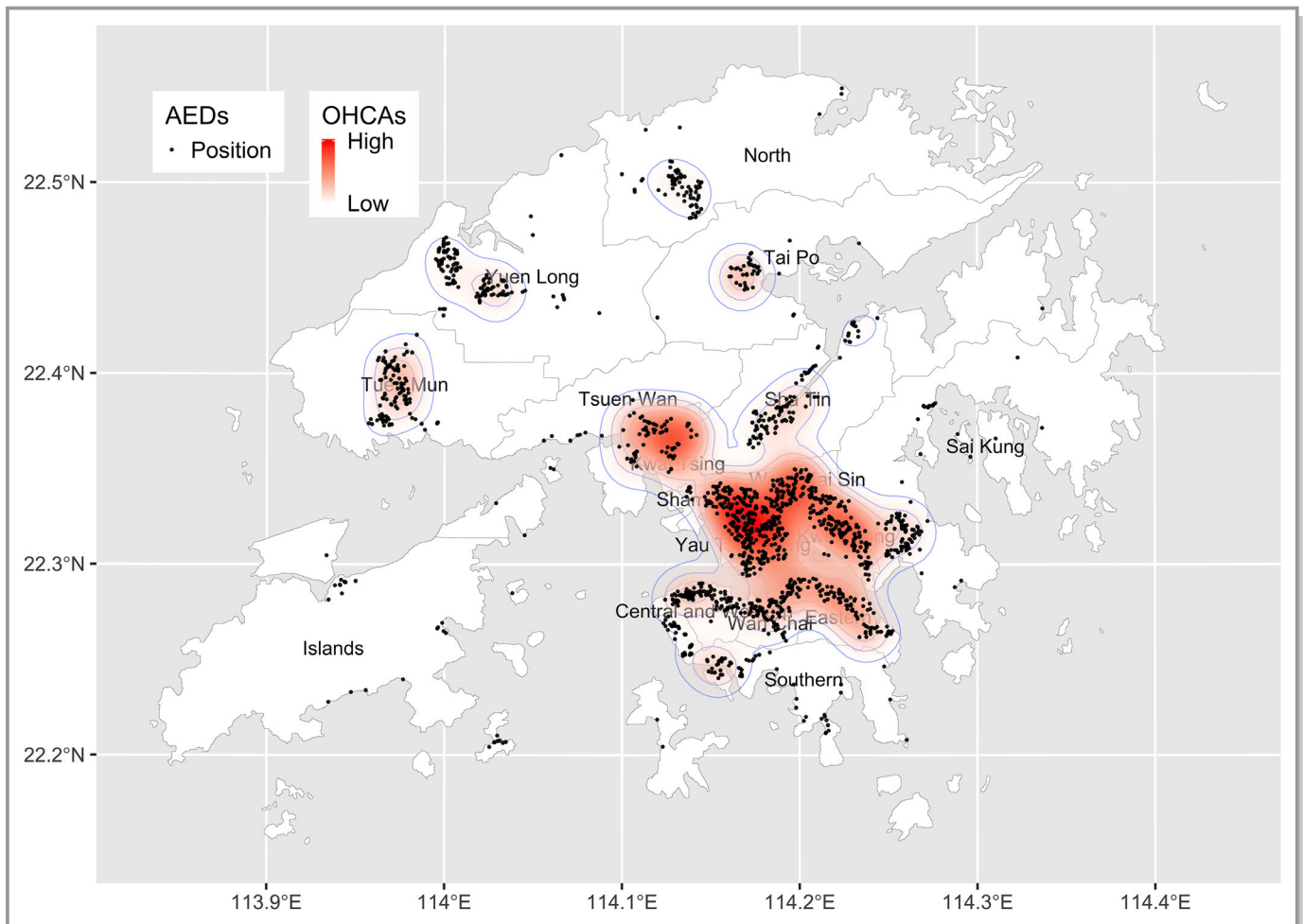


Figure 3. Hotspot map by kernel-density estimation of out-of-hospital cardiac arrests (OHCAs) and the locations of automated external defibrillators (AEDs) of Hong Kong.

is lack of objectivity. In a crowded urban city center, it is impossible to differentiate patients located in or out of range of an AED from a plot (Figure 3). Other tools or models have relied on the calculation of the average distance or coverage rate by measuring the straight line distance between an OHCA and an AED.^{5,6} As shown in this study, however, straight line-based calculations may be inherently inaccurate.

Time to defibrillation is a known predictor of survival in cases of OHCA. The calculation of the distance a bystander has to travel to get to an AED should be as precise as possible. Miscalculation may unnecessarily influence the judgement of policy makers. However, this study has shown that there is significant difference in the results of the spatial relationship of AEDs and OHCA between straight line-based and walking route-based calculation. The walking route distance should be closer to the actual distance between an OHCA and an AED in an urban setting. Using the straight line-based model would overestimate the coverage rate and underestimate the average distance between an OHCA and the closest AED. This is obviously because the straight line-based model does not take

into account the obstacles between the OHCA and the AED in an urban setting. It is therefore recommended that deployment of AEDs in urban settings should be based on the walking route-based model.

Study Limitations

There are several limitations in this study. Because of the lack of compulsory registration of AEDs in Hong Kong, the list of AEDs recruited in this study may be incomplete. Further, the use of the AED found in this study might be limited by temporal inaccessibility.⁷ This is because not all AEDs were 24/7 accessible. As a result, the coverage rate may be hampered and it would adversely affect the timeliness of AED application on a patient with OHCA. The distances calculated by both models were on a horizontal level. In urban cities such as Hong Kong, multistory buildings dominate. The distance between an OHCA and the nearest AED may be underestimated if either the AED or an OHCA occurs in a high-rise building. In fact, studies have shown that patients with an OHCA that occurs in high-rise

buildings might experience delays in emergency medical service response. This would, in turn, undermine their probability of survival.^{14,15} In future studies of AED deployment, incorporation of vertical distances in the calculation is recommended. Historical cases of OHCA were used in the calculation in this study. In theory, the location of an OHCA is unpredictable. The results of calculation on a different set of OHCA may show diverse findings.

Conclusions

The widely used straight line–based calculation of the spatial relationship of AED and OHCA may be inaccurate. A walking route–based model is recommended for studies of optimization of AED deployment.

Disclosures

None.

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