Population Movement and Sudden Cardiac Arrest Location

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Background—Although the benefits of automatic external defibrillators are undeniable, their effectiveness could be dramatically improved. One of the key issues is the disparity between the locations of automatic external defibrillators and sudden cardiac arrests (SCAs).

Methods and Results—From emergency medical services and other Parisian agencies, data on all SCAs occurring in public places in Paris, France, were prospectively collected between 2000 and 2010 and recorded using 2020 grid areas. For each area, population density, population movements, and landmarks were analyzed. Of the 4176 SCAs, 1255 (30%) occurred in public areas, with a highly clustered distribution of SCAs, especially in areas containing major train stations (12% of SCAs in 0.75% of the Paris area). The association with population density was poor, with a nonsignificant increase in SCAs with population density (P=0.4). Occurrence of public SCAs was, in contrast, highly associated with population movements (P<0.001). In multivariate analysis including other landmarks in each grid cell in the model and demographic characteristics, population movement remained significantly associated with the occurrence of SCA (odds ratio, 1.48; 95% confidence interval, 1.34–1.63; P<0.0001), as well as grid cells containing train stations (odds ratio, 3.80; 95% confidence interval, 2.66–5.36; P<0.0001).

Conclusions—Using a systematic analysis of determinants of SCA in public places, we demonstrated the extent to which population movements influence SCA distribution. Our findings also suggested that beyond this key risk factor, some areas are dramatically associated with a higher risk of SCA. (Circulation. 2015;131:1546-1554. DOI: 10.1161/CIRCULATIONAHA.114.010498.)

Key Words: cardiopulmonary resuscitation • death, sudden, cardiac • defibrillators • heart arrest

Sudden cardiac arrest (SCA) remains a leading cause of death in the industrialized world, representing ≈20% of overall mortality.1 Except for a few recent encouraging reports,2–4 survival after SCA remains poor and relatively stable over time, <10%, despite decades of research and major financial investments in resuscitation.5–7

Clinical Perspective on p 1554

Because SCA often presents with an initial ventricular fibrillation,8 external defibrillation has been incorporated as a key factor in the chain of survival since the early 1990s.9,10 Public-access defibrillation programs have thus been developed to make automatic external defibrillators (AEDs) publicly available, allowing rapid early defibrillation.11–17 Although the benefits of AED are undeniable, public use rates remain very low,4,15,18 and thus the effectiveness of such programs could be dramatically improved. One of the key issues is the disparity between the locations of AEDs and SCAs. In Paris, although AED deployment in the community, which started in 1993 with the progressive equipping of EMS ambulances, has been particularly active over the last decade, the choice of where to install AEDs in public places has been driven mainly by empirical considerations (local unguided initiatives). Recent studies have already pointed out the limitations of such an approach, calling for an evidence-based strategy.19

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Although previous studies have identified sites with a higher risk of SCAs, \(^{18-22}\) especially raising the association with train stations and airports, the reliability and determinants of such high-risk places have been only partially explored. In this study, we collected data on SCA locations in Paris. We hypothesized that population movement was a key factor for SCA distribution but could not explain by itself the overall heterogeneity of SCA distribution.

**Methods**

**Population Study**

From January 1, 2000, to July 31, 2010, using the 2 emergency medical services (EMS) systems existing in Paris, we prospectively collected all out-of-hospital SCA cases using a specific case report form.\(^ {23}\) The Paris emergency medical system is a 2-tiered response system coordinated via a unique dispatcher center: a basic life support tier provided by firefighters of the Brigade de Sapeurs Pompiers de Paris, who can apply an AED, and an advanced cardiac life support function provided by ambulance teams with an emergency physician, a nurse, and a paramedic (Service d’Aide Médicale Urgente).

SCA was defined according to the Utstein guidelines as a sudden cardiac death in which specific resuscitation records were available (deceased or successfully resuscitated) after exclusion of cases with obvious extracardiac causes (eg, drug overdose, suicide, drowning, hypoxia, exsanguination, cerebrovascular accident, subarachnoid hemorrhage, and trauma).\(^ {24-26}\)

In the present analysis, we considered SCA occurring in public (nonresidential) areas. We defined public areas as all areas accessible to the general public, including all outdoor locations, public transportation sites, schools, and commercial and civic establishments.

**Geolocalization of SCA**

We used a 2-step approach to localize SCA. First, the exact locations of SCAs were coded geographically and marked on the digital city map. Automated geolocalization was performed first, and all addresses were then verified manually (Google Maps, API Web Services version 3, HTML 5, and JavaScript). Second, we merged geolocalized data with a Parisian grid system established with the Geographic Information System from the Atelier Parisien de l’Urbanisme (http://www.apuru.org), including a defined and grid net with a standardized size of 2020 cells (200×200-m grid cells) over 101 km\(^2\). Of note, the 2 large public parks located in Paris (Bois de Vincennes and Bois de Boulogne) were not considered in this study, which aimed to evaluate an urban setting.

**Population and Landmark Data**

We obtained information for each of the grid cells on the density of the population, population movements, and landmarks in each grid. This involved data collection from different agencies that was coordinated by Atelier Parisien de l’Urbanisme.\(^ {27}\) National and Parisian agencies enrolled in the evaluation of population densities and population movements in Paris were the Syndicat des transports d’Île-de-France, the Direction Régionale et Interdépartementale de l’Équipement et de l’Aménagement, the Observatoire de la Mobilité en Île-de-France, the Institut National de la Statistique et des Études Économiques, the Institut d’Aménagement et d’Urbanisme Île de France, the Paris City Hall, the French Ministry of Transport, and the French Ministry of Education.

First, the density of the population was defined as the number of people living in the area (hundred inhabitants per hectare). Second, in terms of population movements, the flow of persons moving through the grid cell was determined by estimating the daily number of population movements in Paris for each grid cell. Those data were based on the 2001 Enquête Globale des Transports.\(^ {28}\) This survey was carried out from October 2001 to April 2002 under the auspices of the French Ministry of Public Works, Transportation, and Housing. This survey, initiated in 1976, has been carried out by the Institut National de la Statistique et des Études Économiques every 7 to 10 years in Paris (last survey in 2010).\(^ {24}\) The methodology of the survey followed a standardized approach established by the Center d’Études sur les Réseaux, les Transports, l’Urbanisme et les Constructions Publiques. Briefly, a representative sample of 10,500 families were randomly selected in Paris. Nonpermanent residents and people living in hotels or other community locations were not enrolled in this evaluation. Each member of the family was interviewed face to face by an investigator at the family member’s home about all trips he or she had made the previous day through the use of a specific questionnaire (including 106 variables).\(^ {25}\) Children <6 years old were not considered because they were considered to always be escorted by older people. Individual movement was defined as the mean of individual trips taken by living/local population per day between 1 origin and 1 destination, associated with a specific intention or goal. Information on timing, specific itinerary, and mode of transportation (walking, cycling, car, public transportation) was also collected. Intentions were classified as being related to work, shopping, sports/exercise, education, tourism, health, administrative issues, or other activities (eg, other leisure-time activities). For 1 given grid cell, the population movement (per grid cell) was the sum of individual movements of individuals entering into this specific grid cell per day either with the intention of participating in a specific activity or when commuting home. The mean accumulated number of trips taken was estimated at 8,259 134 per day in Paris. The results of the 2010 Enquête Global des Transports survey was very similar to those of the 2001 Enquête Global des Transports survey.\(^ {29}\)

Finally, we obtained information on the evaluation of different city landmarks in each cell. Train stations, exhibition centers, shows and convention centers, museums, public swimming pools or other sport facilities (public or private, outdoor or indoor), places of worship, primary to high schools, large shopping malls (>300 m\(^2\)), hospitals, and tourist attractions (monuments) were considered.

In Paris, the major airports are outside the limit of the city district and could not be studied with the same methodology. To address this issue, we focused on Charles de Gaulle Airport, which is the most crowded airport in France and has a centralized systematic collection of all cases of SCA by EMS. We collected all cases of SCA in this airport from 2000 and 2010. For population movement, no detailed data comparable to Enquête Globale des Transports used in urban Paris were available. Consequently, we used the annual frequency of person visits of this airport (60.5 million passengers in 2010) as the reference value for the flow of population.

**Statistical Analysis**

The subject characteristics were described as mean±SD, proportions, median, and interquartile ranges, as appropriate.

We first provided descriptive data on population density, population movements, and local landmarks in each of the 2020 grid cells. The associations between the number of SCAs and population density and population movements were assessed by use of a general linear model over classes.

Second, to assess whether SCA incidence differed between 2 typical places with the same population movement, we paired each grid cell containing the 6 major train stations (Austerlitz Station, Lyon Station, Nord Station, Est Station, Montparnasse Station, Saint Lazare Station) with the most populated grid cells containing a touristic place (Eiffel Tower, Georges Pompidou Beaubourg Center, Basilica of the Sacré-Cœur–Montmartre, Louvre Museum, Notre-Dame of Paris, Paris Porte de Versailles Exhibition Center) on the closer population movement. We calculated for each pair the difference in the number of SCAs in each cell containing the 6 major train stations and the most populated grid cells containing a touristic place.

Finally, we obtained information on the evaluation of different city landmarks.

We then estimated the risk of having SCA in 1 of the 2020 grid cells containing a specific city landmark (listed above). We used a count model, the negative binomial regression. This model allowed better consideration of the overdispersion compared with the Poisson regression in our sample data. The dependent variable was the number of public SCAs in each grid cell; the independent variable was the presence or absence of the landmarks in the grid cell. We normalized each cell by using the logarithm of population movements (per each unity, ie, the grid cell) as an offset. We provided first a univariate analysis followed by a multivariate analysis.
model and then a multivariate model with adjustment for other landmarks in the grid cell. The relative risk of the cell containing the landmark was the exponential of the regression coefficient, using SAS PROC GENMOD with negative binomial probability distribution and log link function.15,29 We performed a multinomial logistic regression explaining the number of SCAs in 3 categories—no SCA, 1 SCA, ≥2 SCAs—within a grid cell by landmarks in the grid cell and by population movement and population density (considered adjustment variables). We considered population movement and density in 6 categories, as already described. No SCA was chosen as the reference category. We established univariate and multivariate regressions with logistic distribution and general logit link.

All tests were 2 tailed, and values of \( P<0.05 \) were considered to indicate statistical significance. All data were analyzed at INSERM, Unit 970, Cardiovascular Epidemiology and Sudden Death, Paris, with SAS version 9.3 (SAS Institute Inc, Cary, NC).

The authors had full access to data and designed the statistical analysis, had final responsibility for the decision to submit the manuscript for publication, and vouch for the accuracy and completeness of the data and the analyses. This prospective study was conducted according to the Declaration of Helsinki after institutional review board approval.

Results

Characteristics and Clustered Distribution of SCAs in Paris

Overall, of the 8234 out-of-hospital cardiac arrests in Paris, 5296 received EMS resuscitation attempts (Figure 1) and 4176 were presumed to have a cardiac cause (eventually considered SCA): 2921 (69.9%) occurring in a residential location and 1255 (30.1%) occurring in a public location. Baseline characteristics of public SCAs are described in Table 1. Among all cardiac arrest occurrences in Paris, those occurring in public places had more attempts compared with those occurring at home (85.7% versus 55.4%; \( P<0.0001 \)). Among those SCAs that occurred in public places, the proportion considered for resuscitation was very similar across different public locations: 83.7% in train stations compared with 86.5% in others areas (\( P=0.41 \)). The proportion of SCA was observed to be higher in the morning and afternoons (representing 56% of the overall SCAs occurring in 30% of the day).

Figure 2 shows the locations of all 1255 SCAs in public places over the 2020 Parisian grid cells. The mean number of SCA occurring in 1 grid cell was 0.62, varying from 0.56 in a grid cell including a school to 9.93 for a grid cell including a large train station. Among public SCAs, 478 cases (38.1%) occurred in public facilities such as train stations, malls, or museums, whereas 777 (61.9%) took place outside of such facilities, mostly on the sidewalk. The SCAs were scattered around the city with a highly heterogeneous frequency distribution, with many SCAs clustered in areas: 50% of SCAs occurred in 9% of the Paris total area. We noted a particularly high density of SCAs near the 6 major train stations where 12% of SCAs occurred (0.75% of the total Paris area). This distribution was stable over 3 sequential periods of 40 months.

Population Density and Population Movement

The incidence of SCA was evaluated across the classes of population density and population movements (Figure 3). The mean number of public SCAs by grid cell was not significantly associated with population density, varying from 0.33 to 0.78 SCA per grid cell for the first and the sixth class, respectively (\( P \) for trend=0.4). In contrast, when considering population movements, we observed a highly significant association between the number of public SCAs and the different classes of population movements, with a 6-fold difference: the mean number of public SCA by grid cell varying from 0.21 to 1.11 SCAs per grid cell for the lowest and highest classes of population movement, respectively (\( P \) for trend <0.001).

Population Movement and Specific Locations

We analyzed the 6 most visited places in Paris, which accounted for a very similar population movement number compared with the 6 major train stations (median, 26930.0 versus 24591.5 per day and grid cell; \( P=0.06 \)). The median number of SCAs per grid cell was almost 5-fold lower in the tourist sites (4.5 versus 22.5; \( P=0.03 \); Figure 4).

Using a multinomial logistic regression model (Table 2), we explored the extent to which SCA occurrence was influenced by landmarks in cells after adjustment for the population movement and the population density of each grid cell. In univariate modeling, we observed that the odds ratio for having ≥2 SCAs in grid cells containing a train station was 5.76 (95% confidence interval [CI], 4.14–8.01; \( P<0.0001 \)) higher than in grid cells without this landmark. Grid cells containing large shopping malls or exhibitions were also significantly associated with the occurrence of ≥2 SCAs compared with grid cells without those landmarks. In terms of demographic characteristics, in univariate analysis, categories of population density and categories of population movement were associated with the occurrence of ≥2 SCAs.

In multivariate analysis, with other landmarks in each grid cell and demographic characteristics included in the model,
categories of population movement remained significantly associated with the occurrence of ≥2 SCAs (odds ratio, 1.48; 95% CI, 1.34–1.63; \( P < 0.0001 \)), whereas categories of population density were no longer associated. Grid cells containing train stations remained significantly associated with the occurrence of ≥2 SCAs (odds ratio, 3.80; 95% CI, 2.66–5.36; \( P < 0.0001 \)), whereas shopping malls or exhibitions were no longer significantly associated with the occurrence of ≥2 SCAs. In contrast, in multivariate analysis, grid cells containing primary to high schools were negatively associated with the occurrence of ≥2 SCAs (odds ratio, 0.65; 95% CI, 0.48–0.89; \( P = 0.01 \)).

As a sensitivity analysis, we also performed a negative binomial regression model (Table I in the online-only Data Supplement) to explore the extent to which SCA occurrence was influenced by landmarks in cells normalized by the population movement of each grid cell (population movement used as an offset). In a multivariate model accounting for landmarks and population movements, large train stations were significantly associated with the occurrence of SCA (relative risk, 2.60; 95% CI, 1.69–4.01; \( P < 0.0001 \)).

Overall, 67 SCAs occurred in Paris Charles de Gaulle Airport during the same period (2000–2010), giving a frequency of occurrence of 0.12 per million in Charles de Gaulle Airport.

**Discussion**

Our findings provide a better understanding of the extent to which SCAs occurring in public places may be clustered in a large city, with 12% of SCAs occurring in 0.75% of the total Paris area, emphasizing why population movement is crucial to consider, with very few events occurring in less frequented areas. To the best of our knowledge, our study is the first to provide information on population movements in addition to population density. We demonstrated that the population movements was a major determining factor of such heterogeneity, much more than variations in population density. Finally, our results strongly suggest that beyond simply population movements, some areas (major train stations) remain at particularly high risk for SCA occurrence. These data should help optimize AED placement in the community by concentrating AEDs in high-risk areas for SCAs such as train stations.
Stability in the incidence of SCA within geographic areas has been demonstrated. Accordingly, identifying high-risk places for SCA should be considered a reliable method to guide optimal AED location to eventually increase the cost-effectiveness of such programs. For this, a better understanding of high-density SCA areas is needed to provide evidence to the medical community and policy makers to guide strategies for optimal AED deployment, especially in concentrating AEDs in high-risk areas for SCA and acknowledging that some large areas do not need to be so well equipped. The hypothesis that population movement was a highly influential factor, driving “hot spots” for SCA, was strong, although this has not yet been formally tested, mainly because of the lack of reliable data on population movements. Data from different urban Parisian agencies gave us the unique opportunity to explore this question; we demonstrate the extent to which SCA density was associated with population movements and that this association remained significant after adjustment for different landmarks in each grid cell (including train stations) and demographic characteristics. Further attention should be given in the future to those locations with the highest population movement.

As a result of our main finding, that population movement is a major determinant of SCA distribution, we observed that large train stations are particularly high-risk areas for SCAs and confirm that in the setting of a large urban European area, clustered distribution is observed. These data are highly consistent with previous publications that demonstrated an association between major train stations and SCA. A differential proportion in resuscitation attempted by EMS (according to the location of SCA) may have led to a significant reporting bias. This has not been observed, however, with a very similar proportion of SCA with resuscitation attempted being observed in different public places (train stations versus areas other than train stations). Accordingly, in public places, population movement appears unlikely to be a surrogate for an increased likelihood of having a SCA that is witnessed and thus more likely to undergo resuscitation.

Our data add to this prior literature by providing the extent to which those associations were driven by population movements. Consequently, our results are in line with prior literature on the location of SCA. Associations between SCA incidence and population density have been tested in the setting of residential
In quantifying the association between SCA occurrence and the level of population movements, our findings may be particularly useful to provide a strong rationale for AED deployment in the community, targeting high-risk areas.

In 2005, North American guidelines recommended implantation of AEDs in sites “where the probability of cardiac arrest occurring is at least once in every 5 years.” European guidelines considered areas with at least 1 SCA every 2 years candidate sites for AED placement. However, these guidelines were based on limited evidence. Recent data, available since 2009, also elegantly demonstrated the limitation of using such an approach, and these recommendations were finally deleted in the recent updated guidelines. When we look at the history of AED deployment in Paris, it is interesting to observe that this has been carried out independently of any evidence-based approach. For example, the 20 city halls of the different districts were the first public places equipped with AEDs; during our study period, no SCAs at all occurred in these locations. Overall, a relatively consistent pattern of deployment of almost 1000 AEDs in public places from 2000 to 2010 has been observed. For example, the first AEDs were installed in 2005 in major train stations, eventually providing a very similar level of coverage compared with well-known tourist sites in Paris such as the Eiffel Tower and the Musée du Louvre. This contrasts with the actual pattern of SCA distribution seen in our study. This finding emphasizes the point that AED placement may be substantially improved, emphasizing the importance for policy makers and the medical community to consider that AED distribution should followed the SCA distribution on the basis of evidence such as that provided in this study.

Our study also reports additional and interesting findings, suggested by our descriptive approach and confirmed by our modeling. Population movements cannot be the only explanation for the high rate of SCAs in some public areas. Compared with the most tourist-visited sites in Paris, large train stations (with, however, very similar population movements) had a much higher frequency of SCAs. Our approach, based on a count modeling (negative binomial regression), showed a highly significant association between SCA and major train stations, which is attenuated only when considering population movements in the model. Possible explanations include particular physical activity at train stations, which is known to favor ventricular arrhythmias, especially among untrained middle-age men. Another hypothesis may be postulated concerning the associated psychological stress associated with public transportation areas (train stations or airports), mainly related to timing departure issues. Third, particulate pollution in these areas may possibly play a role. Finally, populations in train stations

<table>
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<th>Features</th>
<th>SCA Category</th>
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<th></th>
<th></th>
<th>Multivariate</th>
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<tr>
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<td></td>
<td>OR (95% CI)</td>
<td>P Value</td>
<td>OR (95% CI)</td>
<td>P Value</td>
<td></td>
</tr>
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<td>Population density (per 1 category)</td>
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<td>1.30 (1.20–1.41)</td>
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<td>1.08 (0.97–1.19)</td>
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<td>1.32 (1.24–1.39)</td>
<td>&lt;0.0001</td>
<td>1.19 (1.11–1.29)</td>
<td>&lt;0.0001</td>
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<tr>
<td>Primary to high schools</td>
<td>1</td>
<td>1.41 (1.14–1.73)</td>
<td>0.003</td>
<td>1.06 (0.84–1.33)</td>
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<tr>
<td>Large shopping malls</td>
<td>1</td>
<td>2.15 (1.73–2.68)</td>
<td>&lt;0.0001</td>
<td>1.49 (1.17–1.89)</td>
<td>0.05</td>
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<tr>
<td>Exhibitions and shows</td>
<td>1</td>
<td>1.70 (1.31–2.21)</td>
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<td>1.22 (0.92–1.61)</td>
<td>0.21</td>
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<td>Places of worship</td>
<td>1</td>
<td>1.34 (1.01–1.78)</td>
<td>0.05</td>
<td>1.08 (0.81–1.45)</td>
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<td>Monuments, tourist settings</td>
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<td>1.51 (0.69–3.29)</td>
<td>0.15</td>
<td>1.33 (0.58–3.03)</td>
<td>0.73</td>
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<td>Stations</td>
<td>1</td>
<td>2.08 (1.51–2.88)</td>
<td>&lt;0.0001</td>
<td>1.65 (1.18–2.32)</td>
<td>&lt;0.0001</td>
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</tr>
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</table>

SCA categories: 1=1 SCA in the grid cell; 2=≥2 SCAs in the grid cell (cells without SCA used as reference). CI indicates confidence interval; OR, odds ratio; and SCA, sudden cardiac arrest.
are relatively “unselected” in contrast to users of sport facilities who are likely to be younger and in better physical shape and to have been screened by physicians. This may contribute to this higher frequency of events. Of interest, when we look at the number of SCAs in Paris Charles de Gaulle Airport (60.5 million passengers in 2010) during the same period (2000–2010), we observe a frequency of SCAs very similar to that of the train stations: 0.12 per million in Charles de Gaulle Airport compared with 0.08 per million observed in the 6 major train stations in Paris. The very similar findings observed in major train stations and airports reinforce the idea that physical and psychological stress may be a trigger of SCA in those high-risk areas; other socioeconomic factors might also account for higher rates at those areas and need further investigation. Considering that exposure time (waiting time) may be larger in airports compared with those expected in train stations, this could explain (at least in part) the absolute lower rate of SCAs observed in train stations compared with the airport.

Our study contributes to the existing literature on the localization of SCA,19,30,42 with an innovative approach based on population movement. However, we must acknowledge some limitations. First, we studied only SCA with presumed cardiac cause, which could represent a selection bias. However, this population is the likeliest to benefit from AED and represents the main target of public access to defibrillation programs. Second, the low density of SCAs in the majority of grid cells could distort (to a minor extent) the binomial negative model used but with an unlikely overall impact on the results and model fit. Third, according to the Utstein guidelines, we did not collect information on out-of-hospital cardiac arrests not related to SCA and represents the main target of public access to defibrillation programs. Second, the low density of SCAs in the majority of grid cells could distort (to a minor extent) the binomial negative model used but with an unlikely overall impact on the results and model fit. Third, according to the Utstein guidelines, we did not collect information on out-of-hospital cardiac arrests not related to primary cardiac cause.8,25,26 The extent to which those data (additional 20% of cases, in agreement with prior literature) would change our findings seems limited because those noncardiac cases are known to present a very small proportion with shockable rhythm and thus would be less likely to benefit from public AEDs. Fourth, although the classification status of SCA cases (tourists or permanent resident) was not collected during the study, the extent to which movements related to tourism may influence the distribution of SCA in Paris was of particular interest. It could be possible that population movement may have been underestimated in train stations on the basis of a survey of Paris residents alone. However, the 2005 evaluation carried out by the Institut National de la Statistique et des Études Économiques emphasized that tourism frequency was equivalent to 224400 permanent residents (≈11% of the total population of Paris) and that the number of those additional subjects was similar to the number of permanent residents from outside the city (mainly commuting for business purposes).41 Overall, even in one of the most tourist-visited cities worldwide, the influence of tourism on SCA distribution appears limited. Fifth, interesting existing data have demonstrated the influence of neighborhood socioeconomic status on the incidence and management of SCA.44 However, in terms of SCAs occurring in public places, this “time of exposition” (influence of neighborhood socioeconomic status) to neighborhood appears of limited value, especially in a city like Paris with very high population movement and consequently considerable heterogeneity in socioeconomic status. The extent to which the association between SCA and major train station may be driven by different (lower) socioeconomic status needs to be examined in further studies. Sixth, spatial autocorrelation is an important issue that may be considered through a variety of complex analytic approaches guided by novel specific software (eg, SaTScan).45 Although crucial to consider in the field of infectious diseases and pollution effects, in the setting of SCA, this approach remains more debatable. Finally, our study is limited to Paris, and high-risk areas may differ according to the preferred public transportation system of the city/country (mainly major train stations and airports). Although our descriptive results fit extremely well with data from Folke and colleagues15 (in Copenhagen, 19.5% of SCAs occurred in 1.2% of the city area compared with 1.4% in Paris), the extent to which the present results may be generalized to other non-European cities requires further study. The urban and demographic data available for Paris, the population density, and the large number of tourists provided a unique opportunity to assess the relationship between SCA and population movements. This model may not be easy to replicate in other cities.

Conclusions

In providing a systematic analysis of determinants of SCA within a public urban setting, we demonstrated the extent to which population movements may account for the hot spots of SCA observed. Our results also suggested that beyond this key risk factor, some areas show a dramatically higher risk of SCA. This should provide evidence to the medical community and policy makers to guide strategies for optimal AED deployment.

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Disclosures

None.

References


CLINICAL PERSPECTIVE

Sudden cardiac arrest (SCA) remains a leading cause of death in the industrialized world. Survival remains poor despite decades of research and major financial investments in resuscitation. Because SCA most often presents with initial ventricular fibrillation, external defibrillation has been incorporated as a key factor in the chain of survival since the early 1990s. Public-access defibrillation programs have thus been developed to make automatic external defibrillators (AEDs) more widely available. Although the benefits of AEDs are undeniable, the effectiveness of such programs could be dramatically improved. One of the key issues is the disparity between the locations of AEDs and SCAs. Although preliminary data have identified sites with a higher risk of SCAs, the determinants of those areas have not yet been identified and quantified. In this study, we collected data on SCA locations in Paris over a 10-year period. We emphasized the extent to which, in the setting of a large urban area, the distribution of SCA was clustered in major “hot spots.” We demonstrated that the number of population movements was a major determining factor of SCA location. However, beyond population movements, our results strongly suggest that some areas (especially major train stations) remain at particularly high risk for SCA occurrence (5-fold higher risk compared with tourist areas with similar population movements). This should provide evidence to the medical community and policy makers to guide strategies for optimal AED deployment, especially in concentrating AEDs in high-risk areas for SCA.
Population Movement and Sudden Cardiac Arrest Location

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Supplemental Material

Methods

We estimated the risk of having SCA in one of the 2,020 grid-cells containing specific city landmark. We used a count model, the negative binomial regression. This model allowed better consideration of the over-dispersion compared to the Poisson regression in our sample data. The dependent variable was the number of public SCA in each grid-cell; the independent variable was the presence or absence of the landmarks in the grid-cell. We normalized each cell by using the logarithm of population movements (per each unity i.e. the grid-cell) as an offset. We provided first a univariate model and then a multivariate model considering adjustment on other landmarks in the grid-cell. The relative risk (RR) of the cell containing the landmark was the exponential of the regression coefficient, using SAS PROC GENMOD with negative binomial probability distribution and log link function.\textsuperscript{19, 31}

Table Legend

Relative Risk for SCA of Grid-Cells Containing Specific Landmark. Univariate and Multivariate Analyses (Negative Binomial Regression Model). The RR represents the risk of SCA in a grid-cell with specific landmark compared to grid-cell without the considered landmark.

Table

<table>
<thead>
<tr>
<th>Grid-Cell Characteristics†</th>
<th>Grid-Cell, N</th>
<th>SCA, N\textsuperscript{‡}</th>
<th>Univariable RR (95%CI)</th>
<th>P Value</th>
<th>Multivariable RR (95%CI) *</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary to high schools</td>
<td>893</td>
<td>496</td>
<td>0.69 (0.6 - 0.8)</td>
<td>&lt;0.0001</td>
<td>0.73 (0.63 - 0.84)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Large shopping mall</td>
<td>646</td>
<td>531</td>
<td>0.95 (0.82 - 1.1)</td>
<td>0.49</td>
<td>0.93 (0.8 - 1.07)</td>
<td>0.49</td>
</tr>
<tr>
<td>Exhibitions and shows</td>
<td>383</td>
<td>309</td>
<td>0.93 (0.79 - 1.1)</td>
<td>0.41</td>
<td>0.95 (0.8 - 1.12)</td>
<td>0.29</td>
</tr>
<tr>
<td>Place of worship</td>
<td>311</td>
<td>222</td>
<td>0.89 (0.74 - 1.08)</td>
<td>0.23</td>
<td>0.94 (0.78 - 1.13)</td>
<td>0.52</td>
</tr>
<tr>
<td>Train station</td>
<td>258</td>
<td>418</td>
<td>1.82 (1.54 - 2.15)</td>
<td>&lt;0.0001</td>
<td>1.77 (1.5 - 2.09)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Sports facilities</td>
<td>250</td>
<td>161</td>
<td>1.12 (0.9 - 1.39)</td>
<td>0.32</td>
<td>1.16 (0.93 - 1.43)</td>
<td>0.19</td>
</tr>
<tr>
<td>Museum</td>
<td>132</td>
<td>115</td>
<td>0.97 (0.74 - 1.28)</td>
<td>0.84</td>
<td>0.91 (0.69 - 1.19)</td>
<td>0.49</td>
</tr>
<tr>
<td>Hospital</td>
<td>98</td>
<td>57</td>
<td>0.86 (0.62 - 1.19)</td>
<td>0.37</td>
<td>0.93 (0.68 - 1.28)</td>
<td>0.66</td>
</tr>
<tr>
<td>Touristic sites</td>
<td>36</td>
<td>37</td>
<td>1.05 (0.65 - 1.69)</td>
<td>0.84</td>
<td>0.98 (0.63 - 1.55)</td>
<td>0.94</td>
</tr>
</tbody>
</table>

CI denotes confidence interval, RR, relative risk, SCA, sudden cardiac arrest.
†Grid cells are defined as 200*200-m areas.
†Denotes the total number of SCA within a grid cell containing a given landmark. The number of SCA can overlap between the different grid-cell characteristics because one grid-cell can contain several landmarks. Overall, 1,255 SCA occur over 2,020 grid-cells, including 1,555 grid-cells with at least one characteristics/landmark (1,132 SCA) and 465 grid-cells with none of the characteristics mentioned on the table (123 SCA).

*Multivariable model considering adjustment on other landmarks of the grid-cell.