

# Determining Risk for Out-of-Hospital Cardiac Arrest by Location Type in a Canadian Urban Setting to Guide Future Public Access Defibrillator Placement

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**Study objective:** Automated external defibrillator use by lay bystanders during out-of-hospital cardiac arrest rarely occurs but can improve survival. We seek to estimate risk for out-of-hospital cardiac arrest by location type and evaluate current automated external defibrillator deployment in a Canadian urban setting to guide future automated external defibrillator deployment.

**Methods:** This was a retrospective analysis of a population-based out-of-hospital cardiac arrest database. We included consecutive public location, nontraumatic, out-of-hospital cardiac arrests occurring in Toronto from January 1, 2006, to June 30, 2010, captured in the Resuscitation Outcomes Consortium Epistry database. Two investigators independently categorized each out-of-hospital cardiac arrest and automated external defibrillator location into one of 38 categories. Total site counts in each location category were used to estimate average annual per-site cardiac arrest incidence and determine the relative automated external defibrillator coverage for each location type.

**Results:** There were 608 eligible out-of-hospital cardiac arrest cases. The top 5 location categories by average annual out-of-hospital cardiac arrests per site were race track/casino (0.67; 95% confidence interval [CI] 0 to 1.63), jail (0.62; 95% CI 0.3 to 1.06), hotel/motel (0.15; 95% CI 0.12 to 0.18), hostel/shelter (0.14; 95% CI 0.067 to 0.19), and convention center (0.11; 95% CI 0 to 0.43). Although schools were relatively lower risk for cardiac arrest, they represented 72.5% of automated external defibrillator-covered locations in the study region. Some higher-risk location types such as hotel/motel, hostel/shelter, and rail station were severely underrepresented with respect to automated external defibrillator coverage.

**Conclusion:** We have identified types of locations with higher per-site risk for cardiac arrest relative to others. We have also identified potential mismatches between cardiac arrest risk by location type and registered automated external defibrillator distribution in a Canadian urban setting. [Ann Emerg Med. 2013;xx:xxx.]

Please see page XX for the Editor's Capsule Summary of this article.

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## INTRODUCTION

### Background

Out-of-hospital cardiac arrest is a significant public health problem. The annual incidence of emergency medical services (EMS)-treated cardiac arrest in North America is estimated to be 52.1 per 100,000 people.<sup>1</sup> Only 8.4% of these patients survive to hospital discharge. The probability of survival decreases 5% to 6% per minute delay between collapse and defibrillation without cardiopulmonary resuscitation (CPR) and 3% to 4% per minute when CPR is provided.<sup>2</sup> The median time from 911 call to arrival of professional rescuers often exceeds 6 minutes, even in dense urban environments.<sup>3</sup>

### Importance

Public access defibrillation programs distribute automated external defibrillators into the community to facilitate rapid

defibrillation by laypersons before EMS arrival<sup>4,5</sup> and have been associated with impressive survival advantages.<sup>6-10</sup> Despite these efforts, less than 8% of patients with out-of-hospital cardiac arrest in public settings have an automated external defibrillator applied before EMS personnel arrive.<sup>11</sup>

Automated external defibrillator nonuse at a cardiac arrest emergency is a multifactorial problem with potential barriers at many points along the process pathway. However, a necessary first step toward improving the probability of automated external defibrillator use is to optimize geographic distribution so that one exists within a reachable distance of most cardiac arrests. To accomplish this, knowledge of the likelihood of cardiac arrest at different location types within the community is required so that automated external defibrillator placement can be prioritized. The Heart and Stroke Foundation of Canada and the American Heart Association recommend targeted

**Editor's Capsule Summary***What is already known on this topic*

Automated external defibrillator use can improve survival from out-of-hospital cardiac arrest. The placement of automated external defibrillators relative to out-of-hospital cardiac arrest occurrence is unknown.

*What question this study addressed*

A retrospective analysis identified the locations of nontraumatic out-of-hospital cardiac arrest (N=608) and automated external defibrillators during a 54-month period. The locations of out-of-hospital cardiac arrest and automated external defibrillators were compared.

*What this study adds to our knowledge*

Locations with the highest risk for out-of-hospital cardiac arrest were race track/casino, jail, hotel/motel, hostel/shelter, and convention center. Locations with the highest proportion of automated external defibrillators were post-secondary school, elementary/secondary school, residence, fairground, and jail. A mismatch of resource location (automated external defibrillators) to event location (out-of-hospital cardiac arrest) was identified.

*How this is relevant to clinical practice*

Automated external defibrillator distribution relative to the locations of out-of-hospital cardiac arrest requires further study to determine optimal alignment.

placement of automated external defibrillators at public sites with a high likelihood of cardiac arrest<sup>5,12</sup>; however, the cardiac arrest risk associated with different types of locations is not well understood.

**Goals of This Investigation**

The specific objective of this study was to estimate the average annual per-site cardiac arrest risk by location type, using data from Toronto, Ontario, Canada. We also assessed automated external defibrillator deployment in the context of our location-based risk estimates.

**MATERIALS AND METHODS****Study Design**

We conducted a retrospective analysis of a population-based out-of-hospital cardiac arrest registry and used data from the Resuscitation Outcomes Consortium Epistry-Cardiac Arrest database. This study was approved by our institutional Research Ethics Board.

**Setting**

Toronto is Canada's largest city and the fifth most populous city in North America. It has more than 2.6 million inhabitants, which represents approximately 8% of the Canadian population.<sup>13</sup>

**Selection of Participants**

We included consecutive public location, nontraumatic, EMS-treated, out-of-hospital cardiac arrest episodes from January 1, 2006, to June 30, 2010, occurring within Toronto. Patients were identified as having out-of-hospital cardiac arrest if they were evaluated by EMS personnel and had attempts at external defibrillation by lay responders or EMS personnel or chest compressions by EMS personnel or were pulseless and did not receive CPR or attempts to defibrillate.<sup>14</sup> "Public location" was defined as all areas that were not private permanent dwellings. For instance, we included cardiac arrests occurring in public transportation buildings; commercial, civic, and industrial sites; hotels; hostels; schools; public spaces; and recreational areas but did not include episodes occurring in single-family homes, apartments, nursing homes, or retirement residences. Episodes occurring in medical clinics were excluded. Cardiac arrests occurring at outdoor locations such as large parks, lakes, and beaches not clearly associated with a building were also excluded from the analysis. If an outside cardiac arrest episode occurred on the grounds of or immediately adjacent to an identifiable building, it was included in the analysis and attributed to that building type. "Nontraumatic" was defined as any cardiac arrest not caused by blunt or penetrating trauma or burns.

**Methods of Measurement**

The Resuscitation Outcomes Consortium Epistry-Cardiac Arrest is a large, population-based, prospective registry of consecutive, EMS-attended, out-of-hospital cardiac arrests from 11 Regional Coordinating Centers across Canada and the United States. This study used data from the Toronto regional center only. The methods for Epistry have been described in detail elsewhere.<sup>14-16</sup> Briefly, cardiac arrest cases are identified through multiple redundant processes, including automated electronic filtering of ambulance call reports, paramedic identification of cardiac arrest cases for research, regular hand-sorting through paper EMS charts, and electronic queries of EMS records using a variety of data fields. Data are abstracted by trained personnel from various source documents, including the ambulance call report, dispatch center records, and the patient chart, into a Web-based case report form. The form has built-in logic checks to reduce data entry errors. Double data entry is routinely completed on a selection of charts to identify errors and systematic problems with data entry.

In an a priori fashion, we developed a standardized protocol to categorize the location type of each cardiac arrest episode. The categorization protocol was developed through consensus among the investigator team and pilot testing to optimize interrater reliability. The taxonomy of location types was created

by modifying the location categories of the Toronto Employment Survey (Appendix E1, available online at <http://www.annemergmed.com>). Modification was accomplished by collapsing several of the survey categories into 38 more practical categories for the purpose of this study. The Toronto Employment Survey is a tool used by the City of Toronto Planning Division to monitor progress of planning policies and the city's economic health.<sup>17</sup> This survey has been used as a data source to characterize urban infrastructure in other published epidemiologic analyses exploring neighborhood environments and resources for healthy living in patients with diabetes who are living in Toronto.<sup>18</sup>

We used the pick-up location mailing address abstracted from ambulance call report to determine the geographic location of each cardiac arrest episode. To assign each episode to a location category, 2 investigators (J.H.H. and S.K.T.) independently reviewed paramedic descriptions of building type on the ambulance call report source document stored in the Resuscitation Outcomes Consortium Epistry database, verified this by searching for the address with a Google search, and then visually examined the exterior of the pick-up location by using Google Street Views.<sup>19</sup> Disagreements on location category for each episode were then resolved by consensus between the 2 reviewing investigators. We assessed interrater agreement (before consensus) with the  $\kappa$  coefficient.

Data in the Toronto Employment Survey are updated annually by a team of trained surveyors who visit all buildings located in commercial, industrial, institutional, and mixed-use areas throughout Toronto. Data collected include the geographic location of each nonresidential building in the city and characterization of each location with respect to building type and activities taking place at that location. The results of the Toronto Employment Survey represent the most comprehensive count of nonresidential buildings in Toronto.

We used the Toronto Emergency Medical Services registry of automated external defibrillators in the community to determine locations of automated external defibrillators in the community. Although automated external defibrillator registration is not mandatory in Toronto, this database contains all known automated external defibrillator units placed by the Toronto EMS public access defibrillation program or those voluntarily registered by citizens. Each entry in the database contains the name and mailing address of the building where the automated external defibrillator is located. There are notes associated with each automated external defibrillator that describe the exact position of the unit in the building (eg, "The automated external defibrillator is a box on the wall at the main floor security desk"). The automated external defibrillator database reflects all automated external defibrillators registered before September 2009. Using the same categorization scheme used for cardiac arrest locations, 2 investigators (J.H.H. and R.J.) independently categorized each registered automated external defibrillator location type and resolved disagreements by consensus. To quantify automated

external defibrillator coverage, we report the number of unique buildings having at least 1 registered defibrillator associated with that address.

To estimate the risk of out-of-hospital cardiac arrest by location type adjusted for the number of individual sites within each category, we divided the number of cardiac arrests occurring in each location category by the total number of individual sites in each category (information derived from the 2009 Toronto Employment Survey results, personal communication, Bill Warren, City of Toronto Planning Division, 2010). We then used the study period (4.5 years) as a denominator to produce an average annual per site risk of out-of-hospital cardiac arrest, with 95% confidence intervals (CIs).

We used the known distribution of registered automated external defibrillators in Toronto as a case study for application of the cardiac arrest risk estimates derived by our study. To provide insight into the proportional community investment by location type, we calculated the proportion of all registered automated external defibrillators in each location category. To provide insight into the automated external defibrillator coverage of a given location type relative to others, we calculated the ratio of defibrillator-covered buildings (buildings having at least 1 registered automated external defibrillator on site) to the number of individual sites counted by the Toronto Employment Survey for each location category.

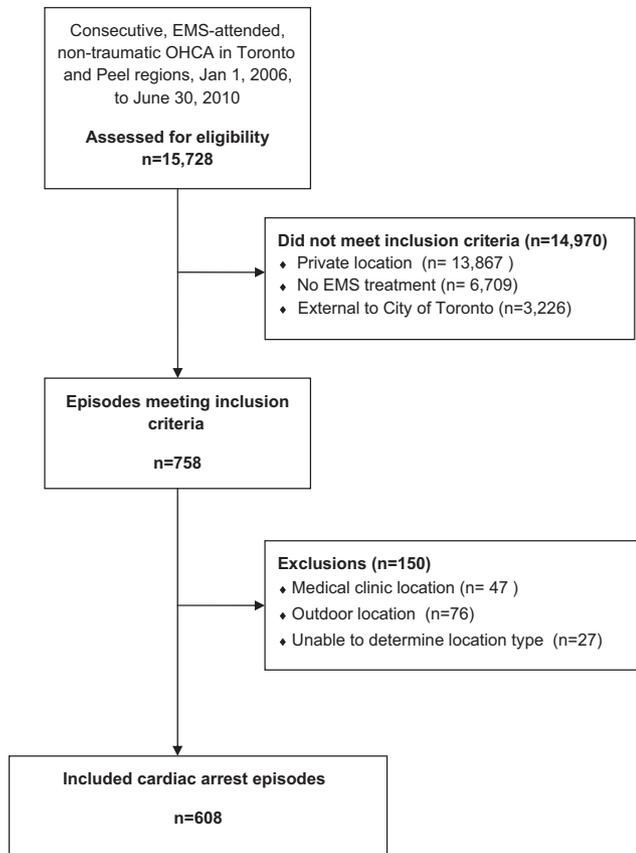
## RESULTS

We included 608 nontraumatic, EMS-treated, out-of-hospital cardiac arrests that occurred in public locations within Toronto during the study period (Figure). The characteristics of the cardiac arrest episodes are shown in Table 1.

### Main Results

The  $\kappa$  coefficient for the classification of out-of-hospital cardiac arrest location was 0.85, indicating very good agreement. Location types with the highest absolute number of out-of-hospital cardiac arrests during the study period in Toronto were retail store ( $n=112$ ; 18.4%), office ( $n=96$ ; 15.8%), hotel/motel ( $n=80$ ; 13.2%), shopping plaza ( $n=51$ ; 8.4%), shopping mall ( $n=44$ ; 7.2%), and industrial ( $n=39$ ; 6.4%). Data from the Toronto Employment Survey indicated there were 27,093 public location sites among the 38 study location categories in Toronto. Location categories with the highest number of sites in Toronto were retail store ( $n=12,469$ ; 46.0%), industrial ( $n=4,727$ ; 17.4%), and office ( $n=3,745$ ; 13.8%). Table 2 shows average annual per-site risk for out-of-hospital cardiac arrest by location category.

The  $\kappa$  coefficient for the classification of automated external defibrillator locations was 0.98, indicating very good agreement. There were 1,587 automated external defibrillator-covered public sites in the registry. Table 3 shows all location categories ranked by the ratio of automated external defibrillator-covered buildings to the total number of sites counted by the Toronto Employment



**Figure.** Derivation of the analyzed cohort of cardiac arrest episodes. *OHCA*, Out-of-hospital cardiac arrest.

Survey in that location category. This ratio represents the relative proportional coverage of each location category in the city, accounting for the total number of sites within that category. Table 4 shows the proportion of automated external defibrillator–covered sites in each location category, reflecting the relative investment of the municipal public access defibrillation program by location type.

**LIMITATIONS**

Interpretation of our analysis must be tempered with an understanding of several underlying assumptions. We assumed a constant number of sites within each category during the study period. It is likely that the number of sites has fluctuated during the study period, and this may have an effect on the validity of the per-site risk estimates. We have also assumed equal cardiac arrest risk across all sites within a given location category. The actual risk for cardiac arrest at one building within a category may differ from that of another building in the same category because of unmeasured variables that differ between the 2 sites.

The automated external defibrillator registry used to apply our risk estimates has some limitations. It includes only automated external defibrillators registered with the municipal public access defibrillation program in our study area and does not include other unregistered devices in the community. This

registry likely overrepresents municipal and public building types such as schools and underrepresents private businesses such as hotels and hostels. In addition, our automated external defibrillator data represent an assessment of defibrillator deployment at one point in time. In reality, their deployment is a dynamic process with additions, relocations, and removals of units occurring over time. Current deployment in the study region is likely to have changed from that reported in our study. However, this historical analysis is useful to understand trends in deployment that may be representative of the current state in other communities.

Unfortunately, a more comprehensive database of automated external defibrillators, registered and unregistered, is not available. The number and location of unregistered automated external defibrillators in Toronto is not known. However, we believe that our analysis using only registered automated external defibrillators is useful despite this limitation because only registered defibrillators are effectively integrated with the 911 emergency response. Unregistered defibrillators are invisible to the 911 dispatcher, and therefore bystanders on the telephone cannot be guided to retrieve and use them in the event of a cardiac arrest emergency. Our results on automated external defibrillator coverage must also be interpreted in the context of our definition of “coverage.” We considered a site covered with an automated external defibrillator if there was at

**Table 1.** Characteristics of included cardiac arrest cases (n=608).

Characteristic	Number of Patients (%)*
Sex	
Male	503 (82.7)
Female	105 (17.3)
Age, mean (SD), y	57.8 (9.5)
Witnessed by bystander	
Yes	312 (51.3)
No	242 (39.8)
Unknown	54 (8.9)
Resuscitation attempted by bystander	
Yes	292 (48.0)
No	307 (50.5)
Unknown	9 (1.5)
AED applied by bystander	
Yes	62 (10.2)
No	507 (83.4)
Unknown	39 (6.4)
Survived to hospital discharge	
Yes	95 (15.6)
No	504 (82.9)
Unknown	9 (1.5)
First cardiac rhythm	
Shockable	220 (36.2)
Not shockable	259 (42.6)
Unknown <sup>†</sup>	129 (21.2)

AED, Automated external defibrillator.

\*All values are No. (%) except for Age, which is mean (SD), y.

<sup>†</sup>This includes patients for whom data are missing and cases in which CPR is initiated but no monitor is ever placed on the chest because of a “Do Not Resuscitate” condition recognized by rescuers after initiation of CPR.

**Table 2.** Location types ranked by out-of-hospital cardiac arrest risk in descending order.

Rank	Location Type	Total OHCA's During Study Period	Total Sites	Average Annual OHCA's per Site	95% CI Lower Limit	95% CI Upper Limit	Number of Sites Required to Yield 1 OHCA per Year
1	Race track/casino	9	3	0.67	0	1.63	2
2	Jail	14	5	0.62	0.30	1.06	2
3	Hotel/motel	80	118	0.15	0.12	0.18	7
4	Hostel/shelter	31	49	0.14	0.067	0.19	8
5	Convention center	2	4	0.11	0	0.43	10
6	Rail station	16	41	0.087	0.020	0.15	12
7	Golf course	6	17	0.078	0	0.29	13
8	Sports arena	17	69	0.055	0.047	0.063	19
9	Shopping mall	44	191	0.051	0.027	0.074	20
10	Sports field	3	19	0.035	0	0.097	29
11	Swimming pool/marina	3	32	0.021	0	0.054	48
12	Community/recreation center	11	147	0.017	0.012	0.021	59
13	Post-secondary school	7	110	0.014	0	0.030	72
14	Other educational establishment (eg, trade school)	1	16	0.014	0	0.047	72
15	Residence (university, religious)	1	20	0.011	0	0.038	91
16	Museum	1	21	0.011	0	0.036	91
17	Shopping plaza	51	1,255	0.0090	0.0031	0.014	112
18	Civic building	1	27	0.0082	0	0.028	122
19	Theater	1	31	0.0072	0	0.024	139
20	Police/fire/ambulance facility	4	128	0.0069	0	0.017	145
21	Library	2	74	0.0060	0	0.023	167
22	Truck station	1	39	0.0057	0	0.019	176
23	Office	96	3,745	0.0057	0.0035	0.0082	176
24	Place of worship	22	1,024	0.0048	0	0.0094	209
25	Private club	1	51	0.0044	0	0.015	228
26	Elementary and secondary school	15	868	0.0038	0	0.0076	264
27	Car parking	1	76	0.0029	0	0.0099	345
28	Gas/automotive station	16	1,605	0.0022	0	0.0042	455
29	Retail store	112	12,469	0.0020	0.0010	0.0027	501
30	Industrial	39	4,727	0.0018	0.0012	0.0023	556
31	Zoo/botanical garden	0	2	0	0	0	—
31	Farm	0	2	0	0	0	—
31	Fairground	0	2	0	0	0	—
31	Military barrack	0	4	0	0	0	—
31	Airport	0	7	0	0	0	—
31	Dock	0	9	0	0	0	—
31	Bus station	0	25	0	0	0	—
31	Day care/nursery school	0	68	0	0	0	—

— indicates that no cardiac arrest episodes were observed at these locations during the study period.

least 1 defibrillator on site. The actual number of defibrillator units required to adequately cover a location probably depends on many factors, including the size and structure of building and the number of people present at the location. Variable automated external defibrillator requirements from site to site were not included in our analysis.

## DISCUSSION

We have estimated the annual per-site risk for out-of-hospital cardiac arrest by location type in Toronto. We found that race track/casino complexes, jails, hotels, hostels, convention centers, rail stations, golf courses, sports arenas, shopping malls, and sports fields were among the highest-risk locations on the basis of average annual per-site risk. Among

categories containing at least 1 observed cardiac arrest, the estimated per-site risk, expressed as the average annual out-of-hospital cardiac arrests per site, ranged from 0.0018 (95% CI 0.0012 to 0.0023) at industrial sites to 0.67 (95% CI 0 to 1.63) at race tracks/casinos.

Our study area included several small municipal airports and heliports but did not include any major international airports. Specifically, Toronto Pearson International Airport, which is the main international airport serving the Greater Toronto Area, is outside the borders of Toronto, and therefore cardiac arrests at this location were not included in the study.

Although there have been several published analyses of cardiac arrest risk by location type, including some data from Canadian settings, many did not control for the total number of

**Table 3.** Location types ranked by the ratio of automated external defibrillator–covered building count to the total number of sites counted in the Toronto Employment Survey, in descending order.

Rank	Location Type	AED-Covered Buildings*	Total Sites Counted by the TES	Ratio of AED Count to Total Sites	Rank Order on Average Annual Cardiac Arrests per Site
1	Post–secondary school	238	110	2.16	13
2	Elementary and secondary school	913	868	1.05	26
3	Residence (university, religious)	20	20	1.00	15
3	Fairground	2	2	1.00	31
4	Jail	4	5	0.80	2
5	Other educational establishment (eg, trade school)	11	16	0.69	14
6	Farm	1	2	0.50	31
6	Convention center	2	4	0.50	5
6	Zoo/botanical garden	1	2	0.50	31
7	Sports arena	33	69	0.48	8
8	Community/recreation center	66	147	0.45	12
9	Golf course	7	17	0.41	7
10	Swimming pool/marina	12	32	0.38	11
11	Race track/casino	1	3	0.33	1
12	Library	22	74	0.30	21
13	Theater	7	31	0.23	19
14	Police/fire/ambulance facility	27	128	0.21	20
15	Civic building	3	27	0.11	18
15	Dock	1	9	0.11	31
16	Shopping mall	10	191	0.052	9
17	Rail station	2	41	0.0487	6
18	Museum	1	21	0.0476	16
19	Hostel/shelter	2	49	0.0408	4
20	Hotel/motel	4	118	0.0338	3
21	Office	126	3,745	0.03364	23
22	Private club	1	51	0.020	25
23	Place of worship	15	1,024	0.0146	24
24	Industrial	52	4,727	0.0110	30
25	Shopping plaza	2	1,255	0.00159	17
26	Retail store	1	12,469	0.0000801	29
27	Military barrack	0	4	0	31
27	Airport	0	7	0	31
27	Sports field	0	19	0	10
27	Bus station	0	25	0	31
27	Truck station	0	39	0	22
27	Day care/nursery school	0	68	0	31
27	Car parking	0	76	0	27
27	Gas/automotive station	0	1,605	0	28

TES, Toronto Employment Survey.

\*AED-covered buildings=buildings with at least 1 registered automated external defibrillator.

individual sites within each category.<sup>20–23</sup> Analyses not controlling for the number of sites within each category are prone to producing inflated risk estimates in categories with a large number of individual sites (eg, retail stores) and are less generalizable to other communities with different building-type counts.<sup>20</sup> Our results are comparable to those reported by Becker et al,<sup>24</sup> who also controlled for the number of sites within each location category. In this report from Seattle, WA, jails, shopping malls, sports venues, golf courses, shelters, and train stations were similarly identified as having a relatively higher average annual cardiac arrest risk per site compared with other sites. This study also found that schools and retail stores have lower risk for cardiac arrest (0.002 and 0.0005 average annual risk per site, respectively).

Tables 3 and 4 represent 2 perspectives on the current automated external defibrillator deployment situation in our study region. Data in Table 4 demonstrate that 72.5% of registered automated external defibrillators placed by the municipal public access defibrillation program have been located in elementary, secondary, and post–secondary schools. This investment by the public access defibrillation program has resulted in excellent coverage of schools in the community, as evidenced by the automated external defibrillator–covered locations to total sites ratios greater than 1 (Table 3). In contrast, although the category of “offices” received the third-highest distribution of automated external defibrillators, at approximately 8% of the registered automated external defibrillator–covered locations, this category is ranked 21st

**Table 4.** Location-type categories ranked in descending order by proportion of registered automated external defibrillator-covered sites (N=1,587).

Rank	Location Type	AED-Covered Buildings, n	Proportion of Total Registered AED-Covered Buildings (N/1,587), %
1	Elementary and secondary school	913	57.53
2	Post-secondary school	238	15.00
3	Office	126	7.94
4	Community/recreation center	66	4.16
5	Industrial	52	3.28
6	Sports arena	33	2.08
7	Police/fire/ambulance facility	27	1.70
8	Library	22	1.39
9	Residence (university, religious)	20	1.26
10	Place of worship	15	0.95
11	Swimming pool/marina	12	0.76
12	Other educational establishment (eg, trade school)	11	0.69
13	Shopping mall	10	0.63
14	Golf course	7	0.44
14	Theater	7	0.44
15	Jail	4	0.25
15	Hotel/motel	4	0.25
16	Civic building	3	0.19
17	Fairground	2	0.13
17	Convention center	2	0.13
17	Rail station	2	0.13
17	Hostel/shelter	2	0.13
17	Shopping plaza	2	0.13
18	Farm	1	0.06
18	Zoo/botanical garden	1	0.06
18	Race track/casino	1	0.06
18	Dock	1	0.06
18	Museum	1	0.06
18	Private club	1	0.06
18	Retail store	1	0.06
19	Truck station	0	0
19	Bus station	0	0
19	Car parking	0	0
19	Gas/automotive station	0	0
19	Day care/nursery school	0	0
19	Military barrack	0	0
19	Sports field	0	0
19	Airport	0	0

(Table 4) when the ratio of automated external defibrillator-covered offices to the total number of offices identified in the community was considered (n=3,745).

Table 3 highlights other location types well covered with automated external defibrillators, including university residences, fairgrounds, jails, and other educational establishments. Among the most poorly covered location

types were rail stations, museums, hotels, hostels, and offices. This analysis allows us to identify a number of location categories where the per-site cardiac arrest risk is not well aligned with the relative automated external defibrillator coverage. For instance, despite the excellent defibrillator coverage of schools in Toronto, we found the cardiac arrest risk in the elementary and secondary school location category to be relatively low, at 0.0038 (95% CI 0 to 0.0076) cardiac arrests per site per year. To yield 1 cardiac arrest per year on average, a group of approximately 260 elementary and secondary schools would be required. This category was ranked 26th by risk but second by automated external defibrillator coverage ratio. There may be reasons other than cardiac arrest risk to justify priority placement of automated external defibrillators in schools, such as the benefits of early and ongoing exposure to automated external defibrillator and CPR training and the potential number of life-years saved by using an automated external defibrillator on school-aged victims of cardiac arrest. However, the opportunity cost of broadly implementing automated external defibrillators in schools over other much higher-risk location types must be carefully considered from the community perspective. An assessment of community risk should guide a coordinated effort by public access defibrillation programs, the local business community, policymakers, and community stakeholders to ensure availability of registered automated external defibrillators at locations associated with higher risk of cardiac arrest.

We have observed that some higher-risk location types have relatively poor automated external defibrillator coverage. For instance, hotels/motels and hostels/shelters were identified to be among the top 10 location types with respect to average annual incidence of out-of-hospital cardiac arrest (ranked third and fourth, respectively) but were also among the bottom 10 location types by registered automated external defibrillator coverage (ranked 23rd and 24th, respectively). This mismatch may be a consequence of the limited mandate that many municipal public access defibrillation programs have. For instance, there are often restrictions placed on municipal public access defibrillation programs that do not facilitate placing publicly funded automated external defibrillators in privately owned but publicly accessible locations, such as hotels. Location types mismatched with respect to cardiac arrest risk and automated external defibrillator coverage may benefit from a coordinated public-private partnership aiming to create a safe community with risk-guided automated external defibrillator placement, regardless of whether the space is public or privately owned.

The 2010 American Heart Association Guidelines assert that “public access defibrillation programs will have the greatest potential impact on survival from sudden cardiac death if the programs are created in locations where sudden cardiac arrests are likely to occur.”<sup>25</sup> The guidelines present data from several studies,<sup>22,26</sup> suggesting that public access defibrillation programs

can be effective when automated external defibrillators are placed in locations in which the cardiac arrest annual incidence is between 0.2 and 0.5. In practice, it is difficult for most communities to apply this type of recommendation. Local longitudinal data on cardiac arrest occurrence, allowing the identification of high-risk locations, are rarely available. The risk estimates across categories of location type provided by our study may be useful for the many municipalities that have easy access to location-type information through their city planning departments but not detailed, site-specific cardiac arrest data. These municipalities could use our results to prioritize certain location types for automated external defibrillator placement and CPR training.

The best approach is probably a combination of a location-type categorical risk assessment using data such as those provided by this study and individual site risk assessment on the basis of cardiac arrest cluster surveillance. For most municipalities, location type is probably the most accessible variable on which to base decisions about automated external defibrillator placement. If site-specific cardiac arrest data are also available in the community and there are specific individual sites associated with high frequency of cardiac arrest, then these sites should also be prioritized for automated external defibrillator placement and CPR training, regardless of location type.

Location-specific estimates of cardiac arrest risk from our study may guide automated external defibrillator deployment and CPR training in other similar urban settings. It is reasonable to expect that our results will be generalizable to other similar urban settings. However, future work should apply this analytic technique to other urban settings in North America and beyond to better understand the generalizability of location-type risk estimates for cardiac arrest.

Future research needs to determine the component factors driving the observed variability of cardiac arrest risk by location type. Considering the types of locations we found to be high risk, we can hypothesize about potential contributing factors such as the demographics, health status, and socioeconomic status of the typical users of that location type, the population density in a building over time, and the types of activities that are occurring within a location.

A comprehensive solution to the problem of automated external defibrillator underuse must include strategies to optimize placement in the community but must also address barriers to the use of automated external defibrillators in close proximity to a cardiac arrest incident. Simply having an automated external defibrillator close to a cardiac arrest incident does not guarantee that the device will be located, brought to the scene, and properly used in a timely fashion. Future work should explore interventions to effectively embed these lifesaving devices into a coordinated community response to cardiac arrest. We need to ensure that automated external defibrillators are not only well placed in the community but also linked to the 911 system and geographic information systems so

that they can be rapidly identified and accessed and properly applied when needed.

In summary, our estimates of cardiac arrest risk by location type, adjusted for the total number of sites in each category, have identified location types with highest risk for cardiac arrest in a Canadian urban setting. In the particular case of Toronto, we have found that most registered automated external defibrillators have been placed at elementary and secondary schools, which are relatively low risk for out-of-hospital cardiac arrest. We found that other location types with much higher per-site risk estimates for cardiac arrest such as hotels, motels, hostels, shelters, and rail stations were less well covered by registered automated external defibrillators and may benefit from focused community efforts to increase defibrillator availability. Our data may guide public policy for urban settings, specifically as it relates to prioritizing locations for registered automated external defibrillator placement, CPR training, and the establishment of on-site first-responder programs for cardiac arrest.

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**Appendix E1.** Taxonomy of study location as modified from the Toronto Employment Survey Property Parcel Categories.

Study Location Type	Toronto Employment Survey Parcel Categories*
Hostel/shelter	09: Hostel, boarding and lodging houses
Residence (university, religious)	10: Sorority and fraternity houses, university, nurses, interns residences, religious orders, monasteries
Hotel/motel	11: Motel 12: Hotel (may have motel component) 14: Hotel/office/significant retail component
Farm	18: Lands in agricultural production; field crops, market gardening, livestock, etc
Civic building	20: Legislative building 21: Law courts 24: Other unspecified institutions
Library	22: Libraries, archives
Place of worship	23: Places of worship
Museum	25: Art gallery (public), museum, planetarium
Theater	26: Theater, concert hall, cinema
Convention center	27: Convention center, exhibition hall
Community/recreation center	28: Community/recreation centers including YMCA, YWCA
Private club	29: Private clubs: Granite, McGill
Industrial	30: Generating station 31: Hydroelectric right-of-way, transformer installations, and control stations 32: Water purification and sewage treatment plants, water reservoirs, pumping stations (water and sewage), water towers (includes oil and gas pipelines) 33: Sanitary landfill site 34: Transfer station, waste processing plant (incineration, recycling, treatment), hazardous waste plant 35: Maintenance yards: parks and roads maintenance yards and other service facilities not part of other defined facilities 40: Extractive industry: mining, sand and gravel excavation, quarrying including wayside pit 41: Heavy industry: heavy industry includes those production processing uses considered to be noxious because of noise, smell, or heavy fumes, generally a large-scale operation (eg, metal production and fabrication, concrete batching, tanning) 42: General manufacturing: assembly and production of goods and materials; general workshops and printing 43: Research and development/laboratories: product or process development and testing 44: Mixed industrial commercial (mall) 45: Under construction 46: Silos, tanks storage: grain silos, oil/gas tank farms, etc 47: Warehousing: internal storage of goods for distribution. Includes wholesaling and rented storage space 48: Open storage: scrap yards, lumber, car distribution centers, etc 49: Manufacturing/office: a building where the major activity is manufacturing but there is a significant office component (code added in 1992) 68: Retail warehousing (located in an industrial area; looks like warehouse) 75: Switching stations (not Bell office buildings), mechanical buildings, etc
Airport	50: Airport: including hangars, terminals, runways, and other facilities
Rail station	51: Rail station, depot 52: Right-of-way tracks: including marshaling yards and rapid transit facilities, subway station
Truck station	53: Truck depot and terminal
Bus station	54: Bus depot and terminal: including Toronto Transit Commission facilities (bus and street car) storage yards
Car parking	55: Car parking: lot and garage
Dock	57: All docks, harbor facilities: (excludes harbor warehouse facilities and recreational marinas)
Retail store	60: Individual store: any single retail or personal service use occupying a single parcel and not attached to another nonresidential parcel (eg, drive-in restaurant, bank, supermarket) but excluding retail warehousing and automotive-related uses 61: Individual store attached to another nonresidential parcel 62: Individual store attached to another nonresidential parcel with other use above: generally offices or apartments above first floor 63: Multistores or personal services 64: Multistores or personal services with other use above: generally offices or apartments above first floor
Shopping plaza	65: Shopping plaza: a group of comprehensively designed stores providing off-street customer parking in an adjoining parking lot, usually at no charge (open)
Shopping mall	66: Shopping mall: a retail shopping facility with an internal pedestrian access system to the individual stores (closed)
Gas/automotive station	67: Automotive: activities related to the sale and servicing of cars (gas stations, car sales, body shops, etc)
Office	70: Government office building: office building occupied exclusively by all levels of government but excluding legislature or court functions (eg, MacDonald Block, St. Clair East)

**Appendix E1.** Continued.

Study Location Type	Toronto Employment Survey Parcel Categories*
	71: General office building: office building (excluding government office building) that may contain a private small retail component. Includes building of private physicians' offices.
	72: Office building/mixed commercial: similar to general office but with substantial retail/service component (eg, Toronto Dominion Center).
	73: Office building/mix commercial/residential: mixed-use building (eg, Colonnade)
	74: Radio and television stations and broadcasting facilities, cable systems. Includes the CN Tower
	77: Other communications facilities: includes post office and sorting stations
	78: Office building/mixed industrial: a building where the major activity is office but there is a significant manufacturing/warehousing component (Code added in 1992)
Daycare/nursery school	80: Daycare or nursery school
Elementary and secondary school	81: Primary and junior high schools: public and separate
	82: High schools: public and separate
	83: Other private educational establishments: academic, (eg Upper Canada College, cram schools)
Other educational establishment (eg, trade school)	85: Private trade schools: including skill-oriented schools: driving, dancing, computer
Post-secondary school	84: Universities, polytechnicals, colleges
Police/fire/ambulance facility	87: Police, fire, ambulance stations and related facilities
Jail	88: Jails and penitentiaries
Military barrack	89: Military installations: including barracks and camps
Sports arena	90: Stadiums, gymnasias, ice and roller skating rinks, racquet clubs, bowling alleys, curling, hockey arenas
Swimming pool/marina	91: Swimming pools, aquatic sports, recreational marinas
Zoo/botanical garden	92: Zoo, aquarium, botanical garden, arboretum
Race track/casino	93: Race courses (horses, cars, casinos).
Fairground	94: Fairground, amusement park: includes Canadian National Exhibition, Ontario Place
Golf course	95: Golf courses and driving ranges
Sports field	96: Sports fields including court games

\*Numbers correspond to the Toronto Employment Survey parcel categories merged to form the study location type.