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Increased Cardiac Arrest Survival and Bystander Intervention in Enclosed Pedestrian Walkway Systems

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Abstract

Background: Cities worldwide have underground or above-ground enclosed walkway systems for pedestrian travel, representing unique environments for studying out-of-hospital cardiac arrests (OHCAs). The characteristics and outcomes of OHCAs that occur in such systems are unknown.

Objective: To determine whether OHCAs occurring in enclosed pedestrian walkway systems have differing demographics, prehospital intervention, and survival outcomes compared to the encompassing city, by examining the PATH walkway system in Toronto.

Methods: We identified all atraumatic, public-location OHCAs in Toronto from April 2006 to March 2016. Exclusion criteria were obvious death, existing DNR, and EMS-witnessed OHCAs. OHCAs were classified into mutually exclusive location groups: Toronto, Downtown, and PATH-accessible. PATH-accessible OHCAs were those that occurred within the PATH system between the first basement and third floor. We analyzed demographic, prehospital intervention, and survival data using t-tests and chi-squared tests.

Results: We identified 2172 OHCAs: 1752 Toronto, 371 Downtown, and 49 PATH-accessible. Compared to Toronto, a significantly higher proportion of PATH-accessible OHCAs was bystander-witnessed (62.6% vs 83.7%, p=0.003), had bystander CPR (56.6% vs 73.5%, p=0.019), bystander AED use (11.0% vs 42.6%, p<0.001), shockable initial rhythm (45.5% vs 72.9%, p<0.001), and overall survival (18.5% vs 33.3%, p=0.009). Similar significant differences were observed when compared to Downtown.

Conclusions: This study suggests that OHCAs in enclosed pedestrian walkway systems are uniquely different from other public settings. Bystander resuscitation efforts are significantly more frequent and survival rates are significantly higher. Urban planners in similar infrastructure systems worldwide should consider these findings when determining AED placement and public engagement strategies.

Key Words

Epidemiology; Cardiac arrest outcomes; Bystander intervention; Pedestrian walkway systems

Introduction

Out-of-hospital cardiac arrest (OHCA) is a significant public health issue that is responsible for 400,000 deaths in North America annually.[1] Previous studies have focused on measuring OHCA burden and variability across different geographical scales, including cities and regions as a whole,[2-4] neighborhoods within a city,[5-8] and location types defined as a group of individual buildings where similar activities take place.[9-15] Accurate estimates of OHCA risk and survival in different locations are important for developing targeted interventions such as strategic placement of public automatic external defibrillators (AEDs) and improving emergency response.

Certain locations such as casinos and airports are characterized by limited accessibility, which presents a challenge in operationalizing emergency response to OHCAs. These locations are also characterized by potentially higher population density, the presence of many potential lay responders, and a greater proportion of OHCA patients who present with an initial shockable heart rhythm.[16,17] Previous research in these settings has demonstrated the positive impact of readily accessible AEDs[16] and organized first-responder teams on survival.[16,17]

In this paper, we characterize the cardiac arrest and survival characteristics of people who arrest in enclosed pedestrian walkway systems, a novel location type that has not been previously studied. Such walkway systems can be found worldwide, serving as a conduit for pedestrian travel, often as a shelter from the winter elements, and sometimes as a destination for shopping and retail. Furthermore, many cities are expanding or building new walkway systems to accommodate increasing urbanization. Enclosed pedestrian walkway systems share many of the characteristics of casinos and airports, such as limited access points, high population traffic, and the presence of many potential lay responders. However, unlike casinos and airports, they are not served by a designated first responder team or centralized surveillance systems. Our goal is to determine whether OHCAs occurring in enclosed pedestrian walkway systems are different from those occurring in the encompassing city with regards to patient demographics, bystander and prehospital interventions, and survival rates, using data from the PATH underground pedestrian walkway system in Toronto, Canada.

Methods

Study Setting

Toronto is the fourth most populous city in North America with a population of over 2.8 million[18] spread over 630.21 sq km.[19] The PATH in downtown Toronto is the largest underground pedestrian walkway system in the world, connecting more than 50 buildings and office towers, 20 parking garages, 6 subway stations, 2 department stores, 8 hotels, and a railway terminal.[20] It provides links to major tourist and entertainment attractions such as the Hockey Hall of Fame, Roy Thomson Hall (choir and orchestra hall), Air Canada Centre (sports venue for

National Hockey League and National Basketball Association teams), Rogers Centre (sports venue for Major League Baseball team), and the CN Tower. The PATH is home to 30 km (19 miles) of shopping arcades and 371,600 sq m (4 million sq ft) of retail space. There are approximately 1,200 shops and services connected by the PATH, and these businesses employ about 5,000 people.[20]

Study Design and Data Sources

This study was a retrospective population-based cohort study using data from the Toronto Regional RescuNET cardiac arrest database, Rescu Epistry, which is compliant with the Resuscitation Outcomes Consortium Epistry-Cardiac Arrest database and the Strategies for Post Arrest Resuscitation Care database; the methodologies of these two databases are described elsewhere.[21,22] This study was approved by the authors' institutional research ethics board. The boundary data for the City of Toronto and downtown Toronto (Figure 1) was obtained from the City of Toronto Open Data Portal.[23] The PATH website[20] was used to gather information on the extent of the walkway system and the buildings connected to the PATH.

Out-of-Hospital Cardiac Arrest Episode Selection

All consecutive OHCA episodes occurring within the City of Toronto from April 1, 2006 to March 31, 2016 were collected. Of these cases, only treated, atraumatic, public location OHCAs were included. Cardiac arrests were identified as "treated" if they were assessed by paramedics and had attempts at external defibrillation by lay responders or paramedics, or received chest compressions by paramedics. "Atraumatic" cardiac arrests were defined as those not caused by blunt or penetrating trauma or burns. "Public locations" were defined as all locations not including private residences. OHCAs that occurred in nursing homes or other healthcare facility settings were excluded. Locations of eligible episodes were identified using postal code, street addresses, and/or latitude-longitude. OHCAs were excluded if the patient was obviously dead, had an existing do-not-resuscitate (DNR) order, or if the OHCA was witnessed by paramedics.

Geographical Categorization of Cardiac Arrest Episodes

The City of Toronto and downtown Toronto boundaries were defined using shapefiles obtained from the City of Toronto Open Data Portal. The PATH boundary was defined as the outline of streets that are directly adjacent to the buildings connected to the PATH (Figure 1 inset). The maximum distance from a PATH-connected building to the street was 30 m.

Three mutually-exclusive categories of the OHCA data were considered: those that occurred within the City of Toronto but outside of downtown (henceforth referred to as "Toronto"), those that occurred within downtown Toronto but outside of a PATH-accessible location ("Downtown"), and those that occurred in a PATH-accessible location ("PATH"). OHCAs were plotted according to the Universal Transverse Mercator coordinates of the pickup address.

Toronto and Downtown OHCA data were identified using the boundary shapefiles as filters in ArcGIS (Esri, Redlands, CA). To classify the PATH OHCAs, we examined ambulance call records of all OHCAs occurring within 50 m of the PATH boundary and geocoded the PATH-accessible cases to the exact arrest location. The floor information of each OHCA occurring within the PATH boundary was obtained from the ambulance call records whenever available. An OHCA was considered PATH-accessible if it occurred between the first basement floor and the third floor of a building connected to the PATH.

Analysis of Cardiac Arrest Data

Demographics and cardiac arrest episode characteristics for each OHCA meeting the inclusion criteria were retrieved from Rescu Epistry, including the date of the arrest, age and sex of patient, whether the arrest was bystander-witnessed, bystander cardiopulmonary resuscitation (CPR) attempt and AED use, time from 911-call to paramedic arrival, first rhythm analysis by paramedics, first shock by paramedics, presence of a shockable initial rhythm, and survival to hospital discharge.

Two between-group comparisons were made: Toronto versus PATH, and Downtown versus PATH. For each comparison, Student's t-test was used and corresponding p-values were calculated to determine any statistically significant differences in mean age, 911 call-to-arrival, 911-call-to-first rhythm analysis, and 911-call-to-first shock time intervals. Pearson's chi-square test was used and p-values were calculated to identify any statistically significant differences in the proportions of the following metrics: male sex, bystander-witnessed arrest, bystander CPR attempt, bystander AED use, presence of shockable initial rhythm, survival to discharge, survival to discharge stratified by initial rhythm, and rate of bystander resuscitation attempts including CPR and AED use among witnessed arrests. Shockable rhythm included ventricular tachycardia, ventricular fibrillation, as well as those determined to be shockable on initial rhythm check with an AED. All statistical analyses were performed using the PASW software package, version 20 (SPSS Inc., Chicago, IL).

To further characterize OHCA incidence in the PATH-accessible region, geographical clusters of arrests were identified using the Kernel Density tool in ArcMap, and potential temporal trends and/or seasonal variation were examined using the arrest episode dates.

Results

During the ten-year period, a total of 2172 treated, atraumatic, public out-of-hospital cardiac arrests occurred within the City of Toronto, where the patient was not obviously dead, did not have an existing DNR order, or was not EMS-witnessed. Of these, 1752 OHCAs occurred in Toronto), 371 occurred in Downtown, and 49 occurred in PATH (Figure 2). The incidence rates were 0.29, 2.21, and 5.39 OHCAs per sq km per year for Toronto, Downtown, and PATH, respectively.

Demographics and characteristics of the included OHCAs with statistical analyses are reported in Table 1. Comparison between the Toronto and PATH OHCAs revealed no statistically significant differences in age, proportion of males, 911 call-to-first rhythm analysis time interval, 911 call-to-first shock time interval, or survival when stratified by initial rhythm. There were significant differences between Toronto and the PATH in the proportion of OHCAs witnessed by a bystander (62.6% vs 83.7%, p=0.003), bystander CPR attempts (56.6% vs 73.5%, p=0.019), bystander AED use (11.0% vs 42.6%, p<0.001), 911 call-to-arrival time interval (6.3 min vs 5.34 min, p=0.004), shockable initial rhythm (45.5% vs 72.9%, p<0.001), and overall survival to hospital discharge (18.5% vs 33.3%, p=0.009). Among bystander-witnessed OHCAs, significant differences between Toronto and the PATH were also observed in the proportion of cases involving bystander CPR attempts (62.7% vs 78.0%, p=0.045), and bystander AED use (12.6% vs 47.5%, p<0.001).

Comparison of the above metrics between Downtown and PATH revealed a similar pattern. There were no statistically significant differences in the proportion of males, 911 call-to-first rhythm analysis time interval, 911 call-to-first shock time interval, or survival when stratified by initial rhythm. In addition, the difference in 911 call-to-arrival time interval was no longer significant. There were significant differences in age (55.2 years vs 60.4 years, p=0.047), proportion of OHCAs witnessed by a bystander (58.5% vs 83.7%, p=0.001), bystander CPR attempts (53.0% vs 73.5%, p=0.007), bystander AED use (14.1% vs 42.6%, p<0.001), shockable initial rhythm (40.3% vs 72.9%, p<0.001), and overall survival to discharge (18.2% vs 33.3%, p=0.014). Among bystander-witnessed OHCAs, no significant difference was found in the proportion of those involving bystander CPR attempts. However, a significant difference was found in the proportion of bystander-witnessed OHCAs involving bystander AED use (17.4% vs 47.5%, p<0.001).

The hotspot analysis uncovered OHCA-dense clusters within the following PATH-accessible areas: Union Station, a major transportation hub that connects bus, subway, and railway routes; Yonge-Dundas Square, a high-traffic public space; and Roy Thomson Hall, an orchestra hall (Figure 3). Of these, the largest cluster was around Union Station, where 11 of the total 49 PATH OHCAs occurred.

There were no discernible temporal trends in PATH OHCA incidence. However, there was a marked seasonal variability where a much greater proportion of arrests occurred during the winter in the PATH group: 496 out of 1752 (28.3%), 80 out of 371 (21.6%), 21 out of 49 (40.8%) arrests occurred in winter in Toronto, Downtown, and PATH, respectively. Winter was defined as December to February inclusive, the three consecutive months of the year with the lowest daily mean temperatures.[24]

Discussion

In this study, we examined the characteristics of cardiac arrests in the novel setting of an enclosed pedestrian walkway system. We found that OHCAs occurring in the PATH system had a higher incidence rate per sq km per year than the rest of downtown and Toronto, and clustered around location types known to have higher rates of OHCA.[9] The winter months saw the highest PATH OHCA incidence rates, which is not surprising given that the PATH is an indoor infrastructure that offers shelter from the elements. Most notably, cardiac arrests in the PATH were associated with much higher rates of bystander intervention and survival to hospital discharge.

In the PATH, there were significantly higher rates of bystander-witnessed OHCAs, bystander CPR attempt, and bystander AED use, all of which are associated with higher survival.[25,26] We hypothesize that bystanders in the PATH are more willing to help and have more ready access to AEDs. This is supported by the following observations among the subgroup of witnessed arrests: compared to Toronto, there were significantly higher rates of bystander CPR attempts; and compared to Downtown, there were significantly higher rates of bystander AED use despite similar CPR attempts.

Overall survival from OHCA in the PATH was 60% greater than that of Toronto and 80% greater than that of Downtown. The significant increase in overall survival for PATH patients can be attributed to the marked increase in the proportion of patients with a shockable initial rhythm, which is the strongest predictor of OHCA survival.[27,28] A potential contributor to the increased proportion of patients with initial shockable rhythm in the PATH may be the shorter 911 call-to-arrival time coupled with the higher proportion of witnessed arrests; witnessed arrests are likely to have shorter collapse-to-911-call time intervals, which would result in a more pronounced difference in total response time from collapse to 911-arrival and rhythm analysis.

The high rates of bystander-witnessed OHCA are comparable to results observed in casino[16] and airport[17] environments, which share similarities with the PATH in that they are all environments with limited access points and have populations of similar age. The proportion of cases that were bystander-witnessed (83.7% PATH, 85.7% (VF) casino, 86.8% airport) or had an initial shockable rhythm (72.9% PATH, 70.9% casino, 76.3% airport) was similar between the three locations. Survival rates among all OHCAs (33.3% PATH, 37.8% casino, 21.1% airport) and survival rates for those with an initial shockable rhythm (41.2% PATH, 53.3% casino, 25.0% airport) were more varied. The higher rate of survival in the casino is likely reflective of the faster response times: 3.5 min from collapse to defibrillator attachment by first responders and 4.4 min from collapse to first defibrillation, compared to 9.4 min and 10.8 min in the PATH. Somewhat paradoxically, airport OHCAs had the fastest median response time interval of 2 minutes but the lowest survival rate for all cases and for those with an initial shockable rhythm. This difference may potentially be explained by prolonged time to first shock but this metric is unknown in the airport cohort.

Although the PATH lacks a centralized responder team, it showed survival rates comparable to that of the casino and airport environments. This seems to suggest that a combination of security personnel, willing bystanders, and public access AEDs may be as effective as the centralized response teams in casinos and airports.

If the high rates of bystander CPR and AED use are indications of bystander willingness to help, enclosed pedestrian walkway systems such as the PATH are areas where targeted lay responder and public access defibrillation (PAD) programs may yield improvements in survival. As well, organized PAD programs that optimize AED placement may increase their availability for use by willing bystanders.[29-32]

Enclosed pedestrian walkway systems are found in many metropolitan cities worldwide, and to our knowledge, this is the first study of cardiac arrest characteristics in such systems. Similar studies in other cities with walkway systems are required to determine the generalizability of our results. To better characterize the bystander population in the PATH, additional studies identifying factors that compel bystanders to help are needed. This study suggests that AED availability may contribute to increased bystander AED use, and as such, its placement in general should be guided by where arrests occur and intuitive 24/7 access. Future studies should evaluate the optimal such placement of AEDs in enclosed pedestrian walkway systems or other location types with limited access points (such as high-rises[33]) and high bystander response rates, as well as the corresponding cost-effectiveness of such placements.

Limitations

In designing this study, the PATH border and PATH-accessible areas were defined using building boundaries and groupings of building floors found in literature.[34,35] Physical barriers such as stairs and elevators were not taken into account..

There is no available demographic data on the people who use the PATH. The PATH is designed for both population transport and retail shopping; if the intended destinations or stops were retail shops, and transportation facilities, our results contribute to the existing literature of higher rates of OHCAs in shopping malls and plazas,[9,15] and airports, ferry terminals, and train and subway stations, respectively. However, it may be difficult to identify defining characteristics if they were walking to another destination without using the transportation facilities. Similarly, we did not have a profile of lay responders in the PATH. There may be other factors affecting bystander response not captured in this study such as CPR knowledge level and performance quality, as well as the time to AED shock by bystanders, which are important factors in successful OHCA resuscitation.[36-38]

As 11 out of 49 PATH OHCAs occurred at Union Station, our results may be somewhat biased to reflect the arrests occurring at the transportation hub rather than the entirety of the walkway system. However, we believe this finding does not undermine the generalizability of our study because we predict that the majority of walkway systems elsewhere will also include large transportation hubs.

Conclusions

This study suggests that OHCAs in enclosed pedestrian walkway systems are uniquely different from other public settings. Bystander resuscitation efforts are significantly more frequent and survival rates are significantly higher. Urban planners in similar infrastructure systems worldwide should consider these findings when deciding on AED placement and how to engage the lay public.

Disclosures

JEB was an evidence reviewer and worksheet author for the International Liaison Committee on Resuscitation 2015 Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Guidelines. SC has received a speaking honorarium from Zoll Medical, and has received grant funding as Co-PI, Toronto site, Resuscitation Outcomes Consortium. LJM holds the Robert and Dorothy Pitts Chair in Acute Care and Emergency Medicine. TCYC holds grant funding from the Zoll Foundation. All other authors have reported that they have no relationships relevant to the contents of this paper to disclose.

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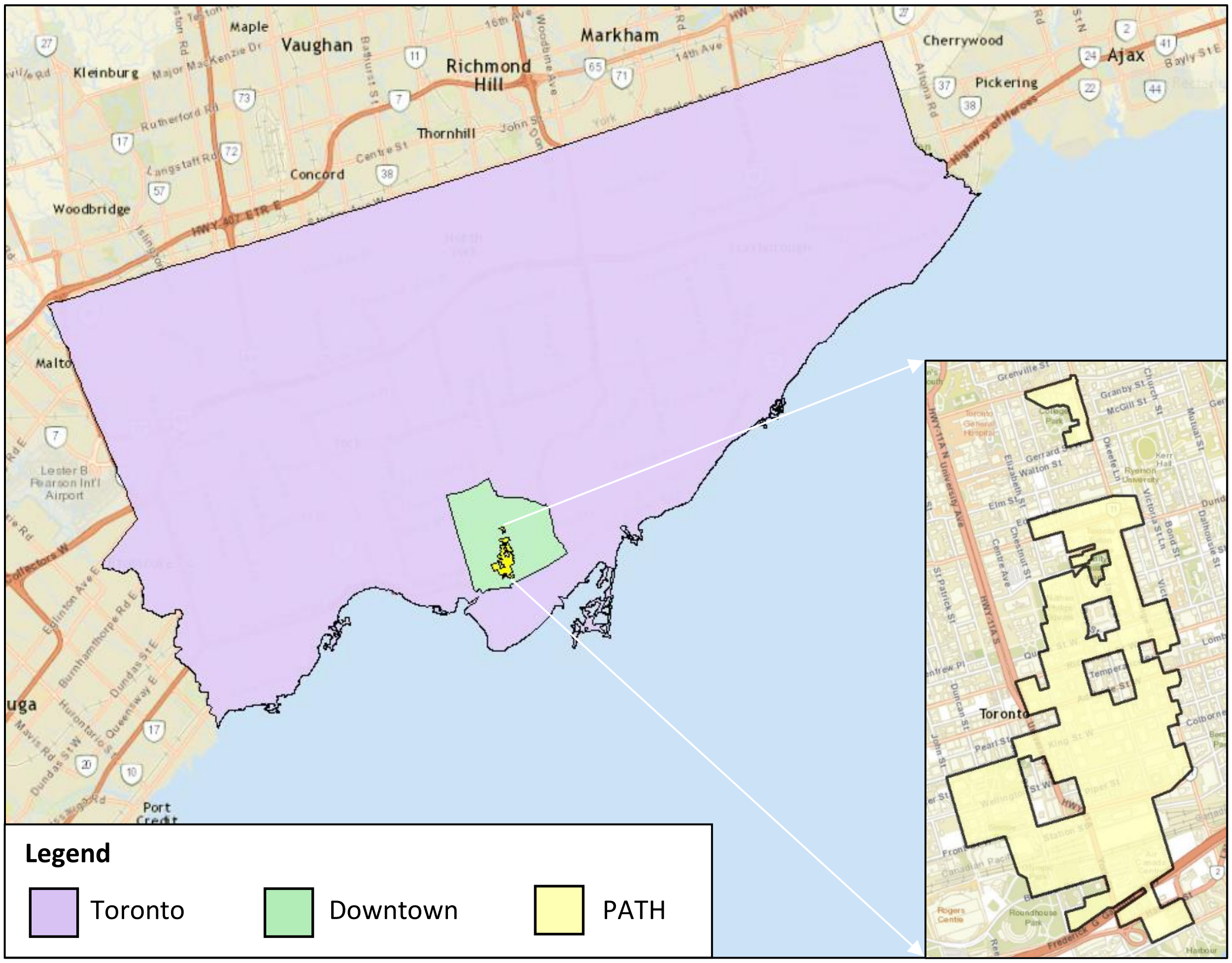
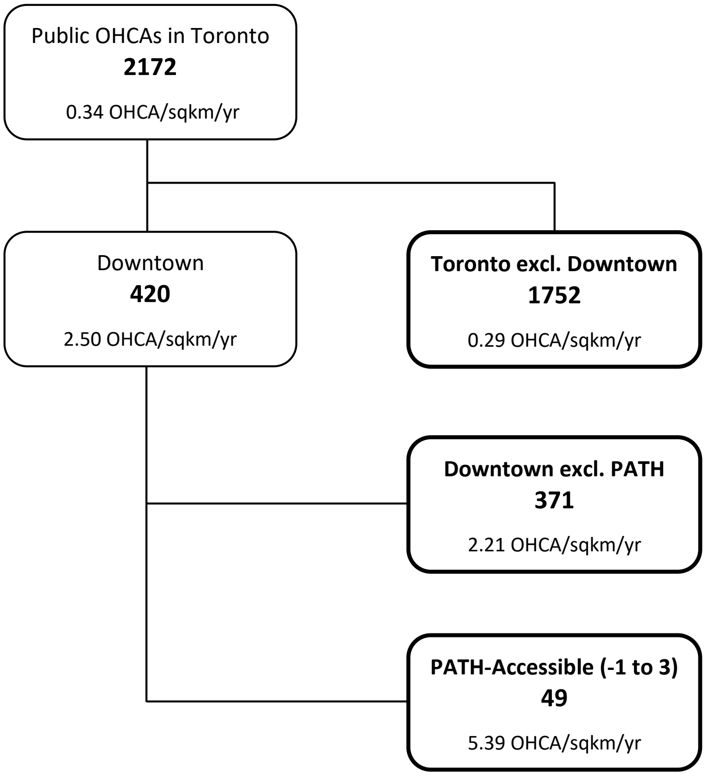
Figure 1. Boundaries for Toronto, Downtown, and the PATH.



Geographical boundaries for Toronto (purple), Downtown (green) and the PATH (yellow), superimposed for comparison of relative size.

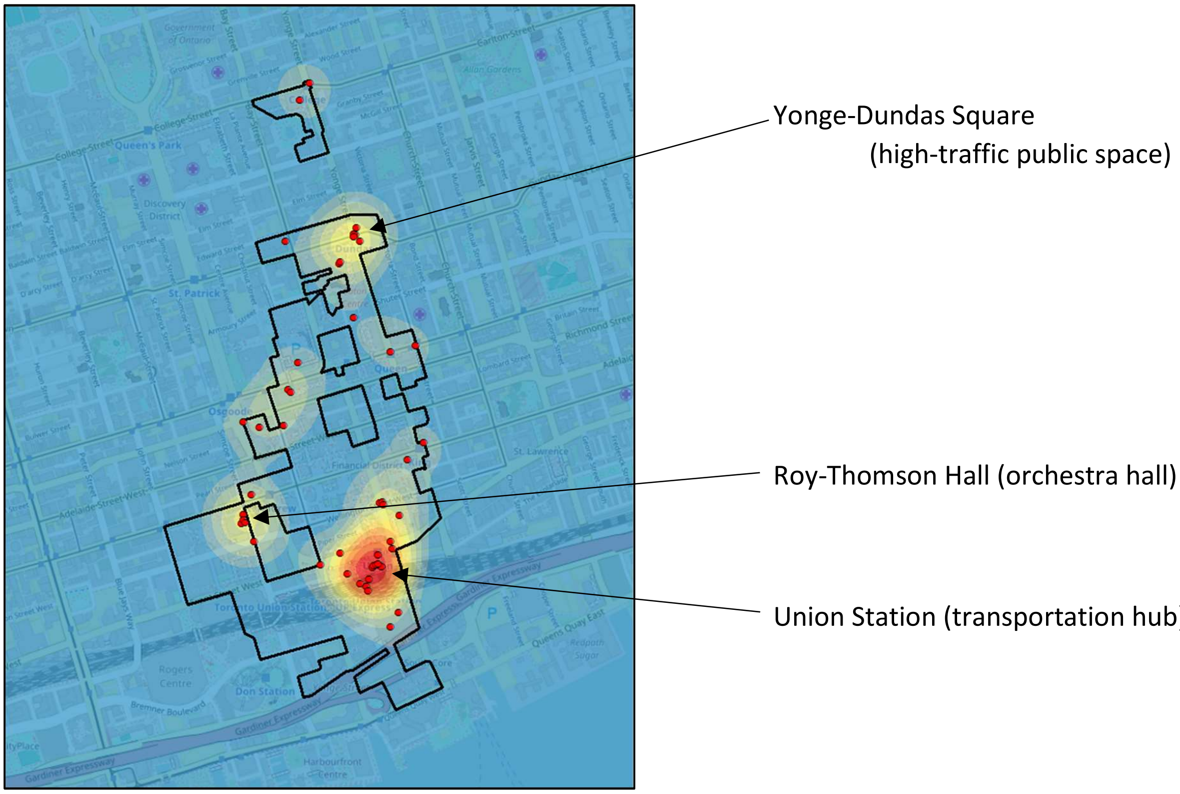
Inset: Enlarged version of PATH boundary, defined as the outline of streets that are directly adjacent to the buildings connected to the PATH. OHCAs were considered PATH-accessible if it occurred within this boundary, and on a floor between the first basement and third floor.

Figure 2. OHCA Episode Categorization.



Number and incidence rates of treated atraumatic public location out-of-hospital cardiac arrests in Toronto, Downtown, and the PATH, from April 2006 to March 2016 inclusive.

Figure 3. OHCA density in the PATH.



Areas of high (red) and low (blue) OHCA density in the PATH (black outline). Red dots represent individual OHCA events.

Table 1. Characteristics of treated atraumatic public location out-of-hospital cardiac arrests in Toronto, Downtown, and PATH, 2006-2016.

Characteristic	PATH-accessible (n=49)		Downtown (n=371)		p-values†	Toronto (n=1752)		p-values‡
Age, mean ± SD, yrs	60.4 ± 18.0		55.2 ± 16.9		0.047	61.5 ± 17.4		0.662
Male proportion, %	89.8		83.6		0.259	80.6		0.106
Bystander Witness, n (%)	41	(83.7)	214	(58.5)	0.001	1091	(62.6)	0.003
Bystander CPR, n (%)	36	(73.5)	196	(53.0)	0.007	991	(56.6)	0.019
Bystander AED use, n (%)	20	(42.6)	51	(14.1)	< 0.001	189	(11.0)	< 0.001
911 Call-to-arrival, mean ± SD, min	5.34 ± 1.44		5.45 ± 2.15		0.736	6.30 ± 2.30		0.004
911 Call-to-first rhythm analysis, mean ± SD, min	9.43 ± 3.71		10.65 ± 10.88		0.486	10.61 ± 4.29		0.089
911 Call-to-first shock*, mean ± SD, min	10.76 ± 4.82		12.61 ± 6.59		0.178	12.93 ± 6.72		0.109
Shockable, n (%)	35	(72.9)	147	(40.3)	< 0.001	786	(45.5)	< 0.001
Survival, n (%)	16	(33.3)	66	(18.2)	0.014	319	(18.5)	0.009
Survival among shockable, n (%)	14	(41.2)	52	(36.1)	0.582	264	(34.2)	0.402
Survival among non-shockable, n (%)	1	(7.7)	11	(5.2)	0.693	43	(4.6)	0.603
Bys. CPR among bystander-witnessed, n (%)	32	(78.0)	138	(64.5)	0.091	683	(62.7)	0.045
Bys. AED use among bystander-witnessed, n (%)	19	(47.5)	36	(17.4)	< 0.001	134	(12.6)	< 0.001

Number of missing/not noted cases (PATH, Downtown, Toronto): age (0,4,7), male sex (0,0,1), witnessed by bystander (0,5,8), received bystander CPR (0,1,1), received bystander AED (2,9,33), 911-call-to-arrival (0,7,27), 911-call-to-first rhythm analysis (10,41,205), 911-call-to-first shock (24,208,854), initial rhythm (1,10,31), survival (1,8,25).

Shockable includes ventricular tachycardia, ventricular fibrillation, and patients where the initial rhythm as interpreted by an AED was listed as shockable.

*Includes only shocks provided by first responders and does not include shocks from bystander AED use

†p-values of comparison between PATH and Downtown; ‡p-values of comparisons between PATH and Toronto

AED = automated external defibrillator; CPR = cardiopulmonary resuscitation; SD = standard deviation.