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Clinical paper

Effect of vertical location on survival outcomes for out-of-hospital cardiac arrest in Singapore



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Abstract

Background: A large proportion of out-of-hospital cardiac arrest (OHCA) cases occur in high-rise residential buildings. This study aims to investigate the effect of vertical location on survival outcomes and response times.

Methods: This is a retrospective study based on data obtained from the Singapore cohort of the Pan-Asian Resuscitation Outcomes Study (PAROS) from January 2011 to December 2014. Study subjects were OHCA cases, unwitnessed and transported by EMS personnel, with known vertical location (floor) data. Traumatic arrests with no resuscitation attempted and missing vertical locations were excluded. The primary outcome was survival to hospital discharge or 30 days post-cardiac arrest.

Results: A total of 5678 OHCA cases were included in the study. The effect of floors on survival was manifested as a U-shaped response. Survival rates of 4.5% for the 4 pooled basement floors and 6.2% for the ground floor (floor 1) were contrasted by a substantial drop to 2.7% at floor 2 and continuing decline to 0.7% at floor 6. In a multivariable model using stepwise logistic regression, both linear ($p = 0.0285$) and quadratic ($p = 0.0018$) floor effects remained significant after adjustment for other significant risk factors, age, bystander witnessed arrest, first arrest rhythm, ROSC on scene/enroute, and EMS response times. Harrell's C-statistic for a predictive model incorporating these variables was 0.933.

Conclusions: Vertical location is associated with OHCA survival probability with a U-shaped response, and this significance remained after adjustment for other significant OHCA variables. This relationship is likely multifactorial and more research is needed to elucidate the various factors.

Keywords: Out-of-hospital cardiac arrest, Vertical location, Survival

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Introduction

Out-of-hospital cardiac arrest (OHCA) is a global health concern, and survival rates for OHCA are known to be very poor.¹ Although improvements have been reported in some recent studies,^{2,3} survival rates remain low in most populations.⁴ The survival rate to hospital discharge for witnessed, shockable OHCA in Singapore was reported to be 11.0% in 2012.⁵

Like Singapore, many cities face multiple challenges in improving cardiac arrest survival due to difficulties of accessing victims in high-rise, densely populated apartment buildings. The challenges of vertical access impacts several factors known to play essential roles in survival outcomes of OHCA such as early cardiopulmonary resuscitation (CPR), early defibrillation and early advanced life support. Response times in initiating these factors may be key to survival.^{6–8} In Singapore, over 90% of the population resides in high-rise apartments.⁹ 68.9% of OHCA cases were reported to have occurred in residential areas and 94.3% in multi-story residences.¹⁰ Although transport distances are relatively short due to the compact landscape and extensive road networks in Singapore,¹¹ emergency medical services (EMS) may nonetheless be delayed due to heavy traffic and unique impediments encountered in high-rise buildings such as access barriers and elevator delays.¹²

A recent Canadian study involving private residences examined relationships between OHCA survival rates and floor of patient contact, and between OHCA survival and delay in patient contact by EMS for cardiac arrests occurring on higher floors.¹² However the study was not able to quantify the direct effect of vertical location on survival per-floor increment due to limited information from paramedic documentation and relatively few cases from higher floors.¹² In Singapore, we have investigated the effect of residential versus non-residential areas on OHCA survival outcomes,¹¹ however, there has not been a study looking at the effect of vertical location on OHCA survival outcomes.

Our primary objective was to determine whether vertical distance from ground floor is associated with risk of survival following OHCA. Secondary objectives involved investigating associations of OHCA clinical characteristics and EMS response times on survival to hospital discharge and developing predictive models of OHCA survival incorporating vertical location in combination with selected demographic and OHCA circumstantial variables.

Methods

Study design and setting

This retrospective cohort study was carried out on Singapore data obtained from the Pan-Asian Resuscitation Outcome Study (PAROS).¹³ PAROS is a prospective international multicenter cohort study involving multiple countries across the Asia-Pacific region.¹³ There are seven participating sites in Singapore which are mainly tertiary hospitals with 24-hour emergency departments (ED). EMS personnel are provided solely by the Emergency Ambulance Services (EAS) of the Singapore Civil Defense Force (SCDF) which is also in charge of fire and rescue services.

Inclusion/exclusion criteria

The population of interest included all OHCA cases in the PAROS registry occurring in Singapore from 01 January 2011 to 31 December 2014. All OHCA patients conveyed by EMS with confirmed absence of pulse, unresponsiveness and apnea were included in the study. OHCA cases witnessed by EMS personnel were excluded because variables designated to be recorded prior to EMS arrival would not be applicable to this group of patients. Exclusion criteria also included patients of known trauma etiology, pronounced dead at scene as well as those with “do not attempt resuscitation” status. Lastly, OHCA cases with incomplete vertical location data were excluded. The study was conducted with waiver of informed consent approved by the Centralised Institutional Review Board and Domain Specific Review Board.

Data collection

In PAROS, data is collected prospectively via a standardized report and entered into a secure, web-based Electronic Data Capture (EDC) system. All cases created in the EDC are assigned a unique case number. EMS data is collected from EMS dispatch and ambulance personnel. EMS times are recorded automatically by the respective dispatch systems with computerized system timings. Hospital data is collected from ED, intensive care units, and hospital wards. Inpatient discharge summaries and death certificate information are also available.¹³ Each participating site has the responsibility to maintain a separate trial log linking case numbers to actual patient identifiers. To prevent a breach of patient confidentiality, care is taken to ensure there are no patient identifiers in the dataset.¹³

Variables collected

Variables definitions follow Utstein’s recommendations^{13,14} and study variables obtained from PAROS are largely pre-hospital variables and interventions. These include information on patient demographics, various time responses from time of call received at the dispatch center to patient arrival at the ED and details on the cardiac arrest.

Outcome measures

The primary outcome collected was 30-day post-cardiac arrest survival or survival to hospital discharge—the most consistently captured outcome among countries¹³ in studies such as ours. Other outcomes included ROSC at the ED and patient status on arrival at ED characterized by type of cardiac rhythm presented and whether breathing and pulse were present. We also looked at various time response performance measures, viz., elapsed times from call to EMS arrival at ED, call to dispatch, dispatch to ambulance arrival, ambulance arrival to patient contact, and elapsed time from ambulance site departure to ED arrival. Subsequent to EMS contact with the patient, time responses were calculated with reference to time of patient contact in order to avoid issues involving discrepancies between measured time intervals and sums of associated sub-intervals.

Data analysis

Baseline descriptive statistics on demographics and EMS variables, and OHCA clinical characteristics were summarized and compared between non-survivors and survivors. Categorical variables were

summarized as counts (%) and compared between non-survivors and survivors using Fisher’s exact test (two-sided). In the presence of sparse data, categorical variables were combined in biologically meaningful ways. Baseline values of continuous variables were summarized as mean and standard deviation or median and interquartile range, as appropriate, and non-survivors and survivors were compared using the two-sample t-test with the Wilcoxon rank-sum test as a robust test against non-normality.

The variable ‘floor vertical scale’ was constructed to allow estimates of proportion surviving based on adequate frequency counts while preserving vertical distances among floors. Frequency counts for floors 1–15 were adequate for analysis purposes, therefore proportion surviving was calculated on an individual floor basis. Frequency counts for basement floors –4 to –1 and upper floors 16–43 were sparse with adequate frequencies attainable only by pooling data for floors –4 to –1, 16–20, 21–25 and >25, respectively. Values of floor vertical scale were specified as follows: 0 (median — 1, basement floors group); 1, 2 . . . 15 (individual floors); and 17, 23, 29 (median floors, pooled floor groups 16–20, 21–25 and >25, respectively). Floor vertical scale was analyzed as a continuous variable.

The linearity assumption for selected continuous variables was investigated — in particular survival versus floor vertical scale. The assumption of linearity of OHCA survival probability as a function of floor vertical scale was investigated graphically by plotting OHCA survival proportion as a function of floor/floor group, and plotting the logit of the

survival proportion, $\ln(p/(1-p))$, as a function of floor vertical scale. Assumptions of linearity of survival and age, and survival and time from ambulance arrival to patient contact as functions of floor/floor group were also checked graphically. Consequently, linear and quadratic terms for vertical scale (floor), and linear terms for age and time from arrival to patient contact were included as candidate predictors in the multivariable logistic regression analyses with the other potential confounders/predictors: demographic/clinical, OHCA characteristics and EMS response time variables.

In an effort to identify factors underlying the U-response in OHCA survival as a function of floor vertical scale, we investigated associations of time from patient contact to ambulance departure and time from ambulance arrival to patient contact with floor/floor group.

Two multivariable stepwise logistic regression analyses were performed: (i) an analysis to identify a subset of independent predictors among study variables available at the time of EMS arrival, and (ii) an analysis to identify predictors from among all variables significant at $p < 0.05$ in univariate analysis. Significance levels to enter and stay of 0.05 were used in both analyses. Analysis results were summarized using odd ratios (95% CI), Wald Chi-Squares and p-values. Harrell’s C-statistic (equivalent to area under the receiver operating characteristic curve) for each model was reported as an index of predictive accuracy. Unless otherwise stated, statistical significance was set at $p < 0.05$.

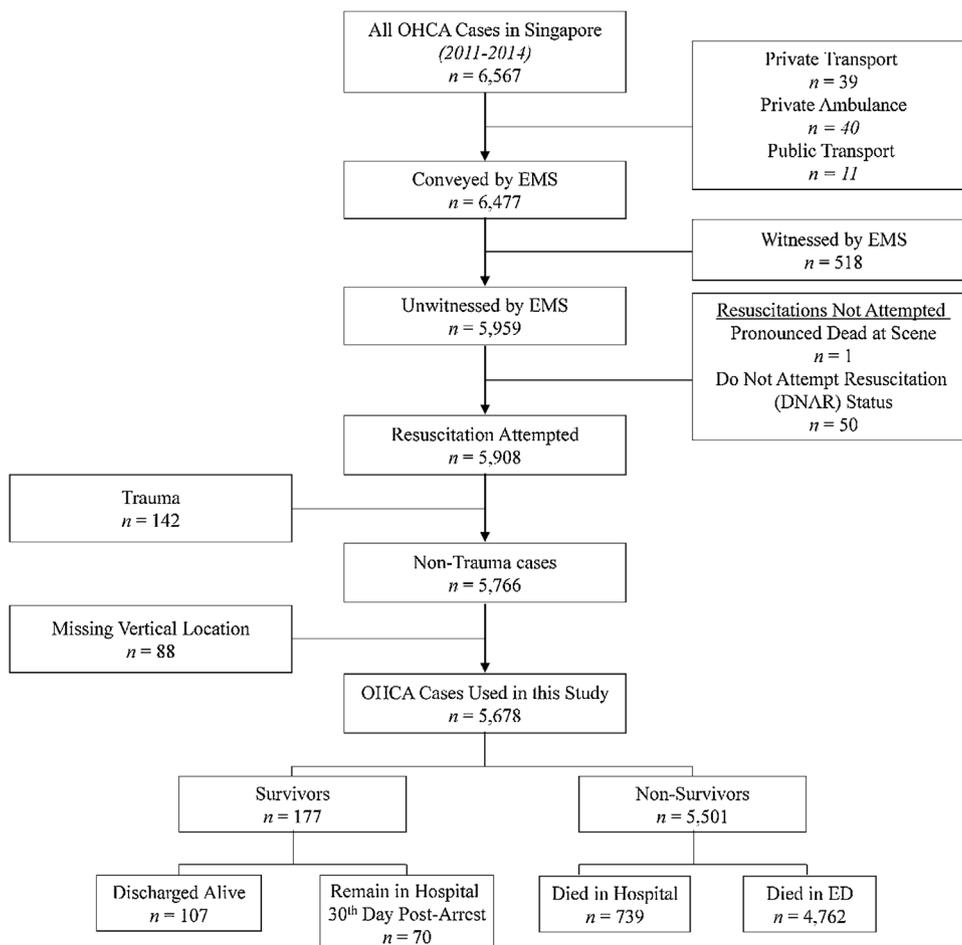


Fig. 1 – CONSORT Flow Diagram.

Missing values occurred in the time variables data. Parameter estimates and statistical significance from multivariable analysis on the full data set ($n = 5678$) did not differ substantively from those on a dataset that excluded the time variables ($n = 5167$); hence, we concluded that missing values among the time variables were not problematic to the analyses.

All statistical analysis was performed using SAS V9.4 (SAS Inc., Cary NC, USA).

Results

From 01 January 2011 to 31 December 2014, a total of 6576 OHCA cases were registered, of which 5766 cases were conveyed but

unwitnessed by EMS personnel, had resuscitation attempted or were of non-trauma etiology. Of these, 88 (1.53%) were excluded because of missing vertical location. Overall, there were 177 (3.12%) survivors out of 5678 cases as shown in Fig. 1. Survivors and non-survivors exhibited significant differences in demographic and OHCA characteristics (Table 1).

A U-shaped association between the survival response and vertical floor scale is shown in Fig. 2 for both the natural (proportion surviving) and the logit scales. Survival rates of 4.5% for the 4 pooled basement floors and 6.2% for floor 1 were contrasted by a substantial drop to 2.7% at floor 2 and continued decline to 0.7% at floor 6. A trend of low but gradually increasing survival rates was observed from floor 7 (1.3%) to pooled floors 21–25 (2.9%) and pooled floors >25 (6.5%).

Table 1 – Comparison of patient demographics, OHCA characteristics, other outcome variables and time responses by survival category.

Variable	All Cases ($n = 5678$)	Survivors ^c ($n = 177$)	Non-survivors ($n = 5501$)	P-value [*]
Demographics				
Floor category, median (IQR)	4 (1, 8)	1 (1, 5)	4 (1, 8)	<0.0001/<0.0001
Age (years), mean (SD)	65.8 (17.7)	58.7 (15.6)	66.0 (17.7)	<0.0001/<0.0001
Residential location, n (%)	4268 (75.2)	83 (46.9)	4185 (76.1)	<0.0001
Male gender, n (%)	3678 (64.8)	133 (75.1)	3545 (64.4)	0.0030
Race, n (%)				0.6581
Chinese	3878 (68.3)	127 (71.8)	3751 (68.2)	
Indian	583 (10.3)	18 (10.2)	565 (10.3)	
Malay	899 (15.8)	22 (12.4)	877 (15.9)	
Others ^a	318 (5.60)	10 (5.65)	308 (5.60)	
OHCA characteristics, n (%)				
Cardiac etiology	4154 (73.2)	146 (82.5)	4008 (72.9)	0.0043
Arrest witnessed by bystander	3240 (57.1)	147 (83.1)	3093 (56.2)	<0.0001
Bystander CPR	2392 (42.1)	107 (60.5)	2285 (41.5)	<0.0001
Bystander AED	138 (2.43)	10 (5.65)	128 (2.33)	0.0106
First arrest rhythm				<0.0001
Shockable	1051 (18.5)	125 (70.6)	926 (16.8)	
Non-shockable	4612 (81.2)	50 (28.3)	4562 (82.9)	
Unknown	15 (0.26)	2 (1.13)	13 (0.24)	
Prehospital defibrillation	1516 (26.7)	131 (74.0)	1385 (25.2)	<0.0001
Mechanical CPR	3244 (57.1)	100 (56.5)	3144 (57.2)	0.8776
ROSC on scene/enroute	310 (5.46)	113 (63.8)	197 (3.58)	<0.0001
Other outcome variables, n (%)				
ROSC at ED	1557 (27.4)	83 (46.9)	1474 (26.8)	<0.0001
Patient status on arrival at ED				
Breathing	86 (1.51)	59 (33.3)	27 (0.49)	<0.0001
Pulse present	282 (4.97)	115 (65.0)	167 (3.04)	<0.0001
Cardiac rhythm				
Sinus or other perfusing rhythm	280 (4.93)	113 (63.8)	167 (3.04)	<0.0001
Shockable	455 (8.01)	28 (15.8)	427 (7.76)	
Non-shockable	4943 (87.0)	36 (20.3)	4907 (89.2)	
Time responses^b (mins), mean (SD)				
Call to dispatch	1.26 (1.63)	1.02 (1.09)	1.27 (1.65)	0.0074/0.0281
Dispatch to ambulance arrival	7.96 (3.58)	6.65 (2.77)	8.00 (3.59)	<0.0001/<0.0001
Arrival to patient contact	2.27 (1.87)	1.79 (1.37)	2.28 (1.89)	<0.0001/0.0006
Patient contact to				
CPR by EMS	0.84 (1.90)	0.42 (0.58)	0.85 (1.93)	<0.0001/<0.0001
AED by EMS	2.21 (2.07)	1.68 (1.44)	2.23 (2.08)	<0.0001/<0.0001
Ambulance departure	13.7 (4.18)	12.0 (3.40)	13.7 (4.19)	<0.0001/<0.0001
Departure to arrival at ED	10.5 (4.86)	9.92 (4.27)	10.5 (4.87)	0.0999/0.2165

^{*} P-value from 2-tailed 2-sample t-test/Wilcoxon rank-sum test; Fisher's exact test (two-sided).

^a Others category comprised of Eurasian and other minority or undefined races.

^b For time responses, cases with erroneous time recordings were excluded.

^c The incident prevalence of survival in our study was 3.12%.

In order to adequately model age as a predictor of survival probability in univariate analysis, a second order (quadratic) equation was required (age, $p = 0.0074$; age² $p < 0.0001$). However, in a preliminary multivariable analysis including both linear and quadratic age effects in the model, and after adjustment for confounders, neither the linear ($p = 0.2095$) nor the quadratic ($p = 0.0575$) effect of age was significant—a result attributed to collinearity. Therefore, the quadratic term was dropped in the final multivariate analyses resulting in a significant linear effect of age in both Model 1 ($p = 0.0083$) and Model 2 ($p = 0.0084$). In addition, we found no significant first or second order interactions at $p < 0.01$ floor vertical scale and any of the following: location type, etiology witness, CPR, AED and FAR.

Association of floor/floor group with time from ambulance arrival to patient contact and time from patient contact to ambulance departure was examined for a U-shaped relationship that would bolster a conclusion of quicker access and departure from ground levels and higher levels in modern buildings with good lifts. However, a U-shaped relationship was not found. We observed either relatively high (ambulance arrival to patient contact) or comparable (patient contact

to ambulance departure) mean and median times when comparing the basement group to floors/floor groups of level 2 and above, with a trend for progressively increasing ambulance arrival to contact and contact to departure times with higher floors. A spike showing substantially reduced arrival to contact and contact to departure times was observed for the ground floor (Fig. 3).

Univariate logistic regression analysis on survival as a function of vertical floor scale resulted in significant linear ($p < 0.0001$) and quadratic ($p < 0.0001$) effects (Table 2). Multivariable Analysis Model 1 was obtained as a parsimonious selection of predictors from a candidate list of variables available at time of EMS arrival using a stepwise regression algorithm with significance levels to enter and stay of $SLE = SLS = 0.050$ (Table 2). Candidate variables selected based on literature review^{10,12} were linear and quadratic effects of floor vertical scale, linear effect of age (the quadratic effect was dropped due to co-linearity), location type (non-residential/residential), gender, race (Chinese, non-Chinese), etiology (cardiac/non-cardiac), arrest witnessed by bystander (Y/N), bystander CPR (Y/N) and bystander AED (Y/N), first arrest

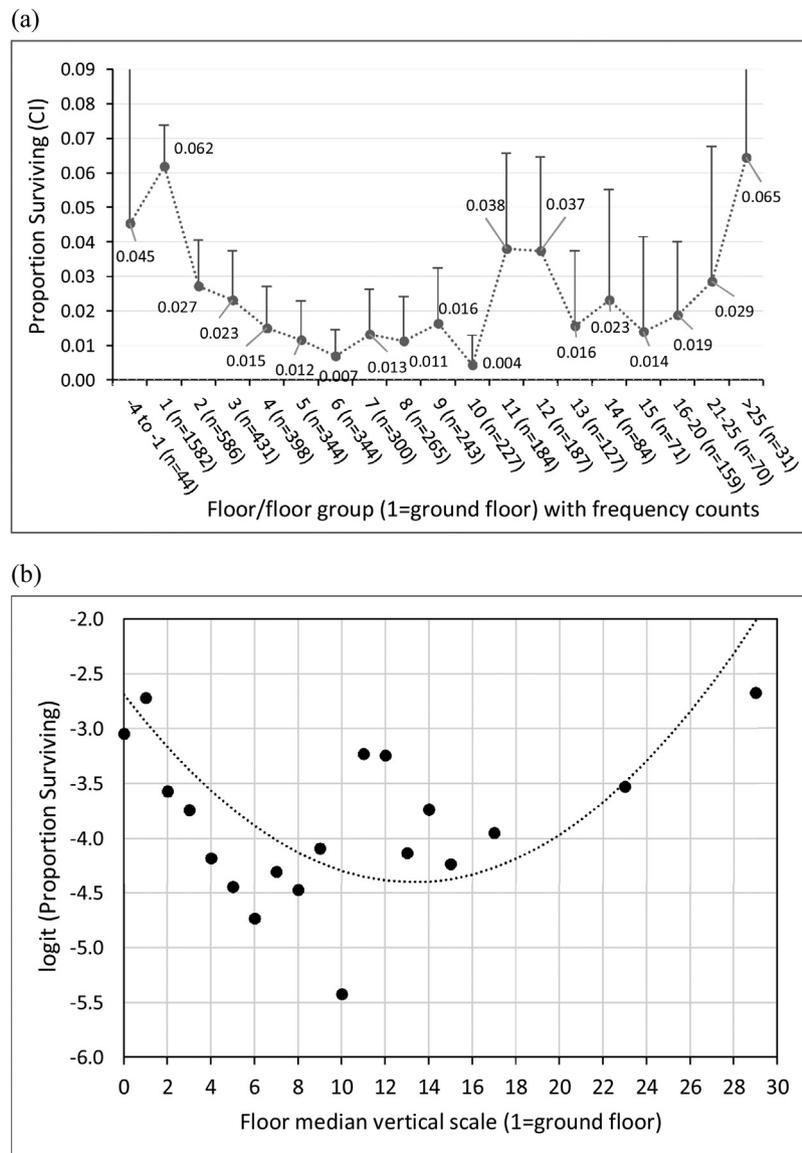


Fig. 2 – (a) Proportion surviving versus floor/floor group. (b) Logit (proportion surviving) versus floor median vertical scale, observed values and second order fitted regression.

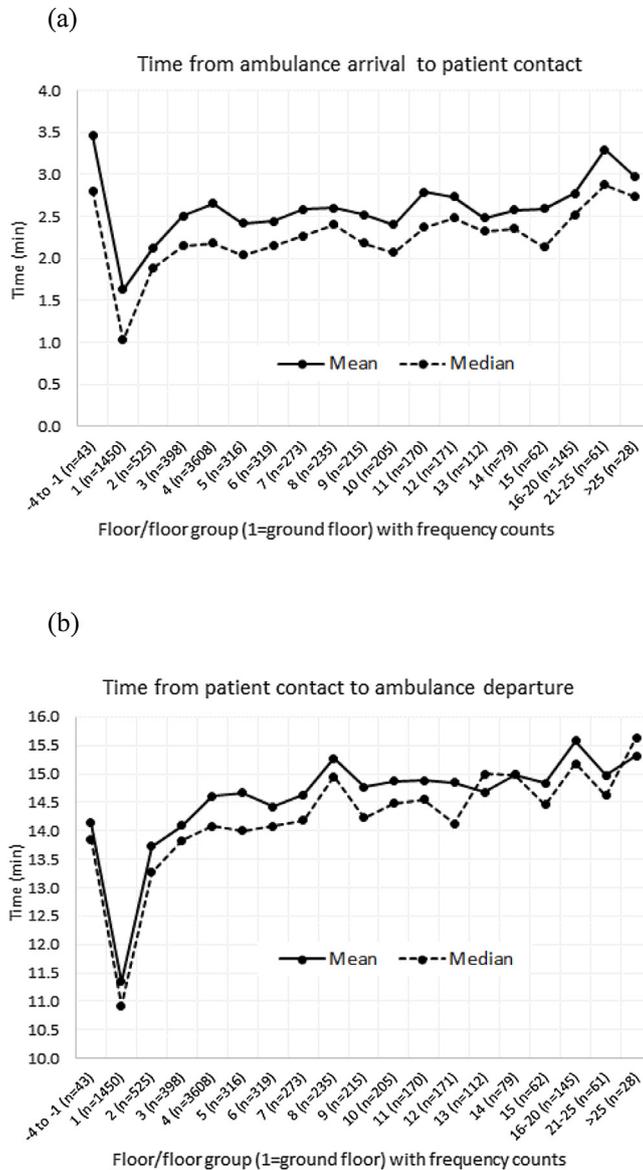


Fig. 3 – (a) Association of Floor/floor group with time from ambulance arrival to patient contact. (b) Association of Floor/floor group with time from patient contact to ambulance departure.

rhythm (shockable/non-shockable), prehospital defibrillation (Y/N), mechanical CPR (Y/N), time from dispatch to ambulance arrival (min), and time from ambulance arrival to patient contact (min). ROSC was excluded from this analysis as it would not be known at the time of EMS arrival. Variables selected by the stepwise algorithm were linear ($p=0.0007$) and quadratic ($p=0.0009$) effects of floor vertical scale, age ($p=0.0083$), race (0.0311) arrest witnessed by bystander ($p=0.0023$) and first arrest rhythm ($p<0.0001$). The Harrell's C-Statistic (95% CI) for Model 1 was 0.829 (0.793, 0.864).

Multivariable Model 2 was obtained using a stepwise selection algorithm (SLE=SLS=0.05) on the set of all candidate variable significant at $p<0.05$ in univariate analysis. Variables selected were linear ($p=0.0043$) and quadratic ($p=0.0002$) effects of vertical floor scale, age ($p=0.0044$), arrest witnessed by bystander ($p=0.0009$), first arrest rhythm ($p<0.0001$), ROSC on scene/enroute (Y/N) ($p<0.0001$), time from dispatch to ambulance arrival ($p=0.0002$)

and time from patient contact to CPR by EMS ($p=0.0065$) (Table 2). The C-statistic (95% CI) for the Multivariable Model II was 0.933 (0.911, 0.955). The two most influential predictive factors were ROSC on scene/enroute and first arrest rhythm category with respective Wald Chi-squares of 313.7 and 76.1, with C-statistic 0.897 (0.871, 0.925).

Discussion

The U-shaped association of vertical location with OHCA survival observed in our study was an entirely unexpected outcome. The relationship between vertical location and survival is multifactorial in nature, complex and likely involves patient, event and system factors. Basement, ground floor and floors >25 resulted in the highest probabilities of survival, with lower survival probabilities reported for midrange floors.

Table 2 – Univariate and multivariable logistic regression analyses investigating floor vertical scale, demographic/clinical variables and EMS time responses on composite endpoint of survival to hospital discharge or 30 days post-cardiac arrest.

Variable ¹	Univariate Analysis		Model 1: Stepwise selection on variables available at time of EMS arrival ^a C-statistic (95% CI) = 0.829 (0.793, 0.864)			Model 2: Stepwise selection on variables significant at <0.05 in univariate analysis ^b C-statistic (95% CI) = 0.933 (0.911, 0.955)		
	OR (95% CI)	P-value	Adj. OR (95% CI)	P-value	Wald Chi-Square	Adj. OR (95% CI)	P-value	Wald Chi-Square
Floor								
Floor vertical scale ^d								
Linear	0.77 (0.72, 0.84)	<0.0001	0.87 (0.80, 0.95)	0.0009	10.9	0.87 (0.79, 0.96)	0.0043	8.16
Quadratic	1.01 (1.006, 1.013)	<0.0001	1.006 (1.003, 1.010)	0.0007	11.5	1.007 (1.004, 1.011)	0.0002	13.8
Demographic/Clinical								
Age (year)								
Linear	1.06 (1.016, 1.107)	0.0074	0.986 (0.975, 0.996)	0.0083	7.00	0.98 (0.97, 0.994) ^c	0.0044	8.13
Quadratic	0.999 (0.999, 1.000)	0.0001						
Location type (Non-residential/ Residential)	3.60 (2.66, 4.86)	<0.0001						
Gender (Male/Female)	1.66 (1.17, 2.34)	0.0041						
Race (Chinese/Non-Chinese)	1.18 (0.85, 1.64)	0.332	0.652 (0.44, 0.96)	0.0311	4.65			
OHCA characteristics								
Etiology type (Cardiac/Non-cardiac)	1.73 (1.17, 2.56)	0.0057						
Arrest witnessed by bystander (Yes/No)	3.77 (2.54, 5.58)	<0.0001	1.96 (1.27, 3.01)	0.0023	9.31	2.31 (1.41, 3.80)	0.0009	11.0
Bystander CPR (Yes/No)	2.15 (1.58, 2.91)	<0.0001						
Bystander AED (Yes/No)	2.62 (1.37, 5.02)	0.0037						
First arrest rhythm (Shockable/Non-shockable)	12.2 (8.76, 17.1)	<0.0001	9.06 (6.28, 13.4)	<0.0001	132.6	6.59 (4.31, 10.1)	<0.0001	76.1
Prehospital defibrillation (Yes/No)	8.40 (5.98, 11.8)	<0.0001						
Mechanical CPR (Yes/No)	0.97 (0.72, 1.31)	0.854						
ROSC on scene/enroute (Yes/No)	47.3 (33.7, 66.2)	<0.0001				45.6 (29.9, 69.5)	<0.0001	313.7
Time responses (min)*								
Call to dispatch	0.86 (0.73, 1.01)	0.062						
Dispatch to ambulance arrival	0.88 (0.83, 0.93)	<0.0001				0.88 (0.82, 0.94)	0.0002	13.9
Ambulance Arrival to patient contact	0.81 (0.72, 0.92)	0.0009						
Patient contact to								
CPR by EMS	0.60 (0.47, 0.77)	<0.0001				0.67 (0.51, 0.90)	0.0065	7.42
AED by EMS	0.78 (0.68, 0.89)	0.0002						
Ambulance departure	0.89 (0.85, 0.93)	<0.0001						
Departure to arrival at ED	0.98 (0.94, 1.01)	0.152						

^a Candidate variables for Model 1: Floor vertical scale (linear and quadratic), Age (linear), Location type, Gender, Race, Etiology, Arrest witnessed by bystander, Bystander CPR, Bystander AED, First arrest rhythm, Prehospital defibrillation, Mechanical CPR, time from dispatch to ambulance arrival, time from ambulance arrival to patient contact. Significance levels to enter and stay of SLE = SLS = 0.05.

^b SLE = SLS = 0.05. As a point of interest, a predictive model consisting of only the two variables ROSC on scene/enroute and first arrest rhythm gave in a C-statistic (95% CI) of 0.897 (0.871, 0.925); adding floor vertical scale linear and quadratic effects increased the C-statistic (95% CI) to 0.909 (0.882, 0.937).

^c The quadratic effect of age was dropped from the multivariable analyses due to collinearity.

^d Floor vertical scale reflects median vertical distance between floors/floor groups: 0 (median –1, basement floors group); 1, 2 . . . 15 (individual floors); 17, 23, 29 (median floors, pooled floor groups 16–20, 21–25 and >25, respectively).

The recent Canadian study¹² that examined the relationship between OHCA survival and vertical floor categorized vertical location only as <3 floors and ≥3 floors which renders any direct comparison of findings impossible. In contrast, our study investigated the incremental effect of vertical location on survival. Our findings are consistent with the recent Canadian study only insofar as both studies demonstrated independent associations of vertical location with survival after adjustment for other variables.¹³

We observed a substantial drop in the probability of survival from the pooled basements and the ground floor to the second floor, with a continuing decline in survival rates through floors 5 and 6 with a relative bottoming out through floor 10. Survival rates for floors 11 and 12 are incongruously high, with an increasing trend initiating at floor 13 to ultimately achieve a survival rate for the floors >25 comparable to floor 1. This was an unanticipated and surprising outcome, and we

can only speculate regarding an underlying cause for this observed phenomenon.

The relationship between the vertical distance and survival is likely multifactorial, depending on the actual way of access to the patient — whether via escalator, elevator, or stairway, and also the characteristics of the population living in different types of buildings. For example, the residents of older residential buildings and low-rise estates tend to be of older age compared to residents of the newer high-rise buildings of >25 floors. In some of the older estates in Singapore with low-rise buildings, stairway access is the only option available to reach the upper floors. This might contribute to the relatively linear association between floor and decline in survival rates for such buildings, as the actual floor number is important in determining time taken to patient contact as well as patient contact to ambulance departure from the scene. On the other hand, in high-rise buildings, elevator delays or elevator mechanics might be the determining factor regardless of floor of contact.

The 'U' response of floor on survival was initially thought to be the result of elevator algorithms for evacuation¹⁵ and designated elevators in high-rise buildings that service only the upper floors in order to improve efficiency and reduce waiting times. These high-rise buildings >25 floors tend to be newer, and therefore also likely to have better elevator mechanics to cater to the upper extremes. The wait at the middle floors in this circumstance could then potentially be the longest, and could explain a longer time taken to patient contact, or from patient contact to ambulance departure from the scene which was significant in multivariable analysis which incorporated variables selected on the basis of clinical relevance. However, this explanation does not seem to be corroborated by observed trends between vertical floor distance and time from ambulance to patient contact and time from patient contact to ambulance departure. For both time variables, trends were observed showing progressively longer times with higher vertical distance for floors 2 and higher with a dramatic spike in time reduction for both time variables at the ground floor.

Undoubtedly there are other factors at play, such as higher socioeconomic status for those living in higher floors which require higher property purchase prices, race distribution patterns (Chinese tends to live in higher floors vs. non-Chinese), observed across the levels of residential estates and etc. Studies have shown that socioeconomically deprived communities had higher incidence of OHCA,¹⁶ and studies that have investigated the incidence of OHCA by ethnicity at a similar area unit level showed reduced¹⁷ or increased¹⁸ risk with ethnicity types. Another possibility as to why patients were more likely to survive at the higher floors is that patients who were dead at EMS arrival were excluded from the analysis, and an unmeasured confounder made survival more likely if a patient was alive upon EMS arrival. This multifactorial relationship between vertical distance and survival is complex and more research is required.

Limitations

There were 511 (9%) erroneous and/or missing data elements for the EMS time responses. Because we measured elapsed time from one time point to another (e.g., from patient contact to CPR by EMS), cases with missing or obviously erroneous data in any of the time recordings were not included in analyses of the various response times.

Due to data collection limitations, we were unable to differentiate high-rise and low-rise apartments or adjust for the total number of floors in a building, or identify if stairway access or elevators were used to achieve patient contact. More research linking building type and our cardiac arrest registry is needed. One possibility could be linking the

PAROS registry to the Urban Redevelopment Authority (URA) Real Estate Information System (REALIS) database based on postal code. REALIS provides comprehensive information on Singapore property and contains a wide range of statistics on even the private residential, commercial and industrial sectors. By so doing, we may be able to obtain more information on building age and determine whether elevators or only stairway access is available.

As with all retrospective observational studies, causality between survival and vertical distance cannot be established by our study. The results of this study may not be generalizable to other countries due to differences in infrastructure such as roads or access, traffic conditions and EMS system differences etc.

Conclusion

Floor at which cardiac arrest occurs is associated with probability of survival, with basements, ground floor and extreme upper floors exhibiting the highest probabilities of survival, and midrange floors exhibiting lower probabilities of survival. The relationship between vertical location and survival is multifactorial and additional research is needed to elucidate the various factors. Interventions aimed at improving access to patients in all floors should continue to be investigated.

Conflict of interest statement

A/Prof Ong has licensing agreement and patent filing (Application no: 13/047,348) with ZOLL Medical Corporation for a study titled 'Method of predicting acute cardiopulmonary events and survivability of a patient'. No further conflict of interests for other authors.

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REFERENCES

1. Stiell IG, Wells GA, Field BJ, et al. Improved out-of-hospital cardiac arrest survival through the inexpensive optimization of an existing defibrillation program: OPALS study phase II. Ontario Prehospital Advanced Life Support. *JAMA* 1999;281:1175–81.
2. Wong MK, Morrison LJ, Qiu F, et al. Trends in short- and long-term survival among out-of-hospital cardiac arrest patients alive at hospital arrival. *Circulation* 2014;130:1883–90.

3. Chan PS, McNally B, Tang F, Kellermann A, CARES Surveillance Group. Recent trends in survival from out-of-hospital cardiac arrest in the United States. *Circulation* 2014;130:1876–82.
4. Nichol G, Thomas E, Callaway CW, et al. Regional variation in out-of-hospital cardiac arrest incidence and outcome. *JAMA* 2008;300:1423–31.
5. Lai H, Choong CV, Fook-Chong S, et al. Interventional strategies associated with improvements in survival for out-of-hospital cardiac arrests in Singapore over 10 years. *Resuscitation* 2015;89:155–61.
6. Larsen MP, Eisenberg MS, Cummins RO, Hallstrom AP. Predicting survival from out-of-hospital cardiac arrest: a graphic model. *Ann Emerg Med* 1993;22:1652–8.
7. Valenzuela TD, Roe DJ, Cretin S, Spaite DW, Larsen MP. Estimating effectiveness of cardiac arrest interventions: a logistic regression survival model. *Circulation* 1997;96:3308–13.
8. Drennan IR, Lin S, Thorpe KE, Morrison LJ. The effect of time to defibrillation and targeted temperature management on functional survival after out-of-hospital cardiac arrest. *Resuscitation* 2014;85:1623–8.
9. Statistics Singapore - Department of Statistics Singapore. (Accessed 29 June 2017 at <http://www.singstat.gov.sg/statistics/latest-data#36/>).
10. Goh ES, Liang B, Fook-Chong S, et al. Effect of location of out-of-hospital cardiac arrest on survival outcomes. *Ann Acad Med Singapore* 2013;42:437–44.
11. Ong EHM, Chan YH, Anantharaman V, Lau ST, Lim SH, Seldrup J. Cardiac arrest and resuscitation epidemiology in Singapore (CARE I study). *Prehosp Emerg Care* 2003;7:427–33.
12. Drennan IR, Strum RP, Byers A, et al. Out-of-hospital cardiac arrest in high-rise buildings: delays to patient care and effect on survival. *CMAJ* 2016;188:413–9.
13. Ong ME, Shin SD, Tanaka H, et al. Pan-Asian Resuscitation Outcomes Study (PAROS): rationale, methodology, and implementation. *Acad Emerg Med* 2011;18:890–7.
14. Cummins RO, Chamberlain DA, Abramson NS, et al. Recommended guidelines for uniform reporting of data from out-of-hospital cardiac arrest: the Utstein style. A statement for health professionals from a task force of the American Heart Association, the European Resuscitation Council, the Heart and Stroke Foundation of Canada, and the Australian Resuscitation Council. *Circulation* 1991;84:960–75.
15. Siikonen M-L, Sorsa JS. Elevator Evacuation Algorithms. Comparing pedestrian movement simulation models for a crossing area based on real world data. Springer; 2011. p. 637–47, doi:http://dx.doi.org/10.1007/978-1-4419-9725-8_57.
16. Dicker B, Garrett N, Wong S, et al. Relationship between socioeconomic factors, distribution of public access defibrillators and incidence of out-of-hospital cardiac arrest. *Resuscitation* 2019, doi: <http://dx.doi.org/10.1016/j.resuscitation.2019.02.022>.
17. Ong MEH, Earnest A, Shahidah N, et al. Spatial variation and geographic-demographic determinants of out-of-hospital cardiac arrests in the city-state of Singapore. *Ann Emerg Med* 2011;58:343–51.
18. Fosbøl EL, Dupre ME, Strauss B, et al. Association of neighborhood characteristics with incidence of out-of-hospital cardiac arrest and rates of bystander-initiated CPR: implications for community-based education intervention. *Resuscitation* 2014;85:1512–7.