Available online at www.sciencedirect.com

Resuscitation Plus

journal homepage: www.elsevier.com/locate/resuscitation-plus

Clinical paper

Resuscitation for out-of-hospital cardiac arrest in Ireland 2012–2020: Modelling national temporal developments and survival predictors

Tomás Barry[a,], Alice Kasemiire[b], Martin Quinn[c], Conor Deasy[d], Gerard Bury[e], Siobhan Masterson[f], Ricardo Segurado[b], Andrew W Murphy[g], on behalf of the Out-of-Hospital Cardiac Arrest Registry Steering Group*

Abstract

Aim: To explore potential predictors of national out-of-hospital cardiac arrest (OHCA) survival, including health system developments and the COVID pandemic in Ireland.

Methods: National level OHCA registry data from 2012 through to 2020, relating to unwitnessed, and bystander witnessed OHCA were interrogated. Logistic regression models were built by including predictors through stepwise variable selection and enhancing the models by adding pairwise interactions that improved fit. Missing data sensitivity analyses were conducted using multiple imputation.

Results: The data included 18,177 cases. The final model included seventeen variables. Of these nine variables were involved in pairwise interactions. The COVID-19 period was associated with reduced survival (OR 0.61, 95%CI 0.43, 0.87), as were increasing age in years (OR 0.96, 95% CI 0.96, 0.97) and call response interval in minutes (OR 0.97, 95% CI 0.96, 0.99). Amiodarone administration (OR 3.91, 95% CI 2.80, 5.48), urban location (OR 1.40, 95% CI 1.12, 1.77), and chronological year over time (OR 1.14, 95% CI 1.08, 1.20) were associated with increased survival.

Conclusions: National survival from OHCA has significantly increased incrementally over time in Ireland. The COVID-19 pandemic was associated with decreased survival even after accounting for potential disruption to key elements of bystander and EMS care. Further research is needed to understand and address the discrepancy between urban and rural OHCA survival. Information concerning pre-event patient health status and inpatient care process may yield important additional insights in future.

Keywords: Resuscitation, Out-of-Hospital Cardiac Arrest, Cardiopulmonary Resuscitation, Registry Data, Statistical Models, Public Health

Introduction

Longitudinal, national level data on out-of-hospital cardiac arrest (OHCA) can provide important insights into the determinants of survival at clinical and systems levels. Ireland is served by a national level OHCA registry with central collation of Utstein type data. At the most recent census in 2022 the population of Ireland stood at more than 5.1 million people.[1] By 2021 there were almost 3,000 OHCA resuscitation attempts by the emergency medical services (EMS) in Ireland each year.[2] In 2021, only 6.1% of these patients survived to hospital discharge.[2] The Irish Out-of-Hospital Cardiac Arrest Register (OHCAR) is the principal source of population level OHCA data in Ireland.[3] National coverage was established in 2012.[3] In turn, the Irish healthcare system has undergone several temporal developments that are relevant to OHCA care since 2012.[4] Such developments include significant public education, training and first responder recruitment campaigns as well as EMS quality improvement initiatives. Notably 2015 and 2016 brought a major reconfiguration of EMS control, that saw multiple independent regional control centres amalgamated into a single national entity known as the 'National Emergency Operations Centre' (NEOC).[4] The year 2020 was also notable as the first year of the COVID-19 pandemic. The initial wave in Ireland occurred between February and July 2020[5] with a national response that included a range of public health and social distancing measures to limit the spread of infection.[6] At international level, the COVID-19 pandemic has been associated with increased OHCA incidence and worse survival outcomes.[7,8] OHCAR provides a key means of examining cardiac arrest care and outcomes over time. OHCAR has provided annual quality

* Corresponding author at: School of Medicine, University College Dublin, Belfield, Dublin 4, Ireland.
E-mail address: tomas.barry@ucd.ie (T. Barry).

https://doi.org/10.1016/j.resplu.2024.100641

improvement data to ambulance services however, no temporal analyses have been conducted to assess the impact of national interventions on survival in Ireland.[4] A 2010 comprehensive systematic review of the predictors of OHCA survival highlighted key factors associated with survival including witnessed events, bystander CPR, shockable initial rhythms, bystander defibrillation, and prehospital return of circulation.[9] The same review also highlighted little improvement in overall survival over time.[9] Further research has highlighted additional factors associated with poor OHCA prognosis including older age, cardiac arrest occurring at home and prolonged duration of CPR.[10] In the Irish context, we sought to interrogate available OHCAR data from 2012 to 2020, describe incidence and survival trends, model predictors of survival and explore the impact of relevant health system temporal developments over this period.

Methods

OHCA care in Ireland

Statutory OHCA care is provided throughout Ireland by the National Ambulance Service (NAS). In the capital (Dublin) metropolitan region EMS care is also provided by Dublin Fire Brigade.[11] EMS clinical emergency care is delivered to individual patients by paramedics and advanced paramedics whose scope of practice is determined by statutory national guidelines.[12] In terms of cardiac arrest EMS treatment, these guidelines reflect the International Liaison Committee on Resuscitation (ILCOR) approach to OHCA resuscitation.[13] Only advanced paramedics can provide intravascular medications and endotracheal intubation.[13] Advanced paramedics are routinely dispatched to OHCA if available, however the minimum crewing standard is at paramedic level and thus advanced paramedics are not always present at OHCA resuscitations. To supplement EMS response, Ireland also has a national voluntary network of community first responders (CFRs) who are equipped with basic life support equipment including automatic external defibrillators (AEDs).[11] These volunteers encompass lay individuals without any medical background, volunteers who have a healthcare background and also off duty EMS staff.[11] Community first responders are dispatched by EMS control to OHCA in an effort to provide early care in the interval between OHCA occurring and EMS arriving to scene. In terms of the onward care of OHCA patients, as of 2023 Ireland had 29 acute hospitals with emergency departments that receive OHCA patients.[14] Key Irish emergency care system temporal developments that are relevant to OHCA care are summarised in supplementary Fig. 1.[4]

OHCAR – The Irish out-of-hospital cardiac arrest register

Comprehensive national level data on the Irish experience of OHCA resuscitation has been gathered by the Irish Out-of-Hospital Cardiac Arrest Register (OHCAR) since 2012.[3] OHCAR employs the internationally agreed Utstein approach to data collection.[15] The primary sources of OHCAR data are EMS dispatch and patient care records from Ireland's emergency medical services. Data regarding survival to hospital discharge and neurological outcome are provided by the receiving hospitals.[3] Previous international research involving OHCAR data has addressed comparisons of key outcomes including survival.[16–18] At national level OHCAR has contributed to research addressing public access defibrillation, geographical disparities, first responders and outcomes in key age cohorts.[19–25]

Study population

The population for this study were patients of all ages who had suffered un-witnessed, or bystander witnessed OHCA during the time period 1/1/2012–31/12/2020 and who had an EMS resuscitation attempt. Patients who had an EMS witnessed OHCA were specifically excluded as they were considered a distinct group to be considered separately in parallel research. The primary outcome of concern was survival to the point of hospital discharge.

Research protocol development and variable selection

At the outset an overall research plan was developed. This then formed the basis for a detailed research protocol which has already been published.[4] A number of key OHCAR variables were identified as those of primary concern in this study. These variables were chosen because their relevance had already been demonstrated in the international scientific literature and because the variables were known to have high levels of data capture.[26] The study team wished to explore whether two key temporal developments were likely to be associated with a significant change in survival. In terms of the first development, the study team hypothesised that the centralisation of EMS control in 2015 and 2016 with a transition from multiple regional control centres to the single national control centre (NEOC) would be associated with survival improvements. In addition, given COVID-19′s detrimental effect on OHCA outcomes internationally we hypothesised that the COVID-19 period would be associated with decreased survival in Ireland with peak impact in 2020. Each of these hypotheses were set out in advance as a component of the study protocol.[4] All analyses were based on the variables and associated categories shown in supplementary Table 1. Variables 1–19 were obtained from OHCAR. Variables 20, 21 and 22 were created using the 'year' variable and represented the key component time periods that were considered potentially significant. Variable 16 was based on the Irish Central Statistics Office classification of urban or rural. Variable 18 the number of adrenaline doses was measured in 1 mg doses. OHCAR variables with multiple associated categories were collapsed to avoid decreased statistical power from analysis of an excessive number of potentially sparse categories. The 'year' variable was treated as a continuous variable to conserve degrees of freedom and statistical power.

Statistical model building

In keeping with the research protocol[4] a series of logistic models were built to explore the outcome of survival to hospital discharge. The effect of each individual variable in the models were summarised using odds ratios and 95% confidence intervals. Initially univariate logistic regression analysis was conducted for each predictor variable. A full multiple logistic model was then fitted incorporating all predictor variables. During the logistic regression model building process, higher order terms (polynomial terms) were added to the model to explore the potential of non-linear relationships between the outcome and the continuous predictors. A refined model was then built via stepwise model selection using the STEPAIC function in R. Several models were built from all possible combinations of predictors by sequentially adding and dropping predictors and ultimately selecting the model with the lowest Akaike Information Criterion (AIC). Finally, the stepwise model was further improved by adding pairwise interaction variables and retaining interactions which improved model fit. Pair-wise interaction terms were individually added to the main effects model and inspected by the statistician for magnitude and improvement in fit, and selected for inclusion on that basis. Each model (initial, stepwise, with interactions) was then evaluated by considering AIC, model deviance and the result of the Hosmer-Lemeshow Goodness of Fit (GOF) test. The predictive ability of the final, best fitting model was then evaluated using 10-fold cross-validation.

Missing data & sensitivity analysis

The proportion of missing data for each variable were documented and evaluated. Sensitivity analyses were conducted using multiple imputation by Multivariate Imputation by Chained Equations in the mice package in R, using ten imputed data sets and methods appropriate for each variable (binomial or polynomial logistic, or linear regressions) were derived. Convergence was verified. Results from complete case analysis and multiple imputation were compared.

Ethical approval

The National University of Ireland Galway, Research Ethics Committee provided ethical approval for this study in advance of data processing and analysis (Reference 2020.01.012; Amendment 2106).

Results

The data contained a total of 18,177 cases (Supplementary Fig. 2). There were some missing data both in the outcome variable of interest ‘survival to hospital discharge’ and in various predictor variables. In all 3,567 cases contained some missing data. Tables 1a and 1b provide an overview of the proportion of missing data for the outcome variable and all predictor variables across the dataset. The outcome variable ‘survival to hospital discharge’ was missing in 0.5% of cases. Across the predictor variables the proportion of missing data ranged from 0.0% to 6.4% (mechanical CPR). Table 1a summarises survival proportions across predictor variable categories. Table 1b provides a summary of continuous predictor variables and illustrates the mean, standard deviation, median and interquartile range for survivors and non survivors. Overall survival was 5.8%. The highest survival was in patients who had bystander defibrillation at 30.0%, however only 6.8% of all patients were in this category. The lowest survival (1.0%) was in those patients who did not have defibrillation attempted at any stage. The majority of patients (68.3%) were in this category. Median age (59.0 versus 68.0 years), call response interval (10.0 versus 13.0 mins) and adrenaline doses (0.0 versus 3.0) were lower in survivors, whereas median shocks delivered (2.0 versus 0.0) were higher in survivors. Fig. 1 summarises the unadjusted OHCA incidence and survival over time. Fig. 1 demonstrates that both incidence and survival trended upwards over the period of the study. supplementary Table 2 presents the results of univariate, unadjusted analysis. During univariate analysis most predictors were associated with small *p*-values, however this was not the case for year, weekday, transition, post transition or COVID period (the year 2020).

supplementary Tables 3 and 2 present the results of the multivariable, adjusted analysis where the outcome variable of interest was ‘survival to hospital discharge’. supplementary Table 3 summarises the results of the full and stepwise modelling. During modelling higher order terms for continuous variables were non-significant which was an indication that a non-linear relationship did not exist. Additionally adding polynomial terms did not improve the model fit. Year was examined using a quadratic transformation, to protect against some degree of non-linearity over time. The result of the Hosmer-Lemeshow Goodness of Fit (GOF) test for the full model (chi-square 56.18, *p*-value < 0.001) and for the stepwise model (chi-square 83.92, *p*-value < 0.001) did not meet the goodness of fit threshold. In moving from the full to stepwise model the variables aetiology, season, and time of day were dropped from the model. The variables that pertained to the centralisation of EMS control (transition period and post transition period) were also dropped at this stage. The model obtained from the stepwise procedure was then further refined by adding interactions that improved model fit. The results of this final model are summarised in Table 2. The result of the Hosmer-Lemeshow Goodness of Fit (GOF) test for this final model demonstrated that the model fits the data well with a chi-square value of 6.57 and a *p*-value of 0.5841. The 10-fold cross validation technique was used to assess the predictive ability of the final model. The prediction accuracy was found to be 96.2% suggesting that the model fits well. The outputs of multiple imputation sensitivity analysis are presented alongside the complete case analysis in Table 2. Complete case and multiple imputation analysis yielded similar results. Table 2 demonstrates that nine of the seventeen variables in the final model were involved in pairwise interactions (airway management, incident location, mechanical CPR, first shock delivered by, shockable initial rhythm, chest compressions started by, total number of shocks, who witnessed collapse and number of adrenaline doses). Thus, the odds ratios for these variables cannot be interpreted in the same fashion as those not involved in interactions.

Figs. 2a and 2b together provide an overall summary of the final model. Fig. 2a illustrates the (adjusted) odds ratios and associated 95% confidence intervals for the final model predictors that were not involved in interactions. In this adjusted model the COVID period was associated with reduced odds of survival (OR 0.61, 95%CI 0.43, 0.87), as were age (OR 0.96, 95% CI 0.96, 0.97) and call response interval (OR 0.97, 95% CI 0.96, 0.99). Amiodarone administration (OR 3.91, 95% CI 2.80, 5.48), urban location (OR 1.40, 95% CI 1.12, 1.77), and year (OR 1.14, 95% CI 1.08, 1.20) were associated with increased odds of survival. The effect estimate for weekday was OR 1.23 (95% CI 1.00, 1.52), and for male sex was OR 1.23 (95% CI 0.97, 1.56). Fig. 2b summarises the final model predictor effects for those predictors that were involved in interactions by comparing effect estimates for a given predictor considering a base case scenario and various other relevant interaction states. Fig. 2b illustrates how effect estimates for individual predictors in the model were altered by different interactions. This is in a theoretical scenario where all other categorical variables within the final model would be at base comparator predictor status (basic airway management, female, other (than home) location, no mechanical CPR, first shock not applicable, non-shockable initial rhythm, EMS initiated CPR, not witnessed, rural location, weekend, no amiodarone administered, not COVID period).

Discussion

The final model incorporated a series of core Utstein elements that capture key aspects of the chain of survival. In terms of examining temporal developments, the predictors that captured the centralisation of EMS control were dropped at the model refinement process. In addition, in the full model, which failed goodness of fit tests, the effect estimates for the transition and post-transition, were associ-

Table 1a – Resuscitation for out-of- hospital cardiac arrest in Ireland 2012–2020: Summary of categorical variables, missing data and survival proportions.

Variable	Missing		Categories			Outcome Available	Survival to Discharge	
	n	%		*n*	%	*n*	*n*	%
Survived to Hospital Discharge	97	0.5	Survived to Discharge	1049	5.8%			
			Died	17,031	94.2%			
			Total	18,080	100.0%			
Airway Management	901	5.0	Basic Management	6524	37.8%	6489	575	8.9%
			Supraglottic device	7348	42.5%	7316	304	4.2%
			Intubation	3404	19.7%	3382	120	3.5%
			Total	17,276	100.0%			
Aetiology	5	0.0	Presumed Other	2548	14.0%	2527	82	3.2%
			Presumed Cardiac	15,624	86.0%	15,549	966	6.2%
			Total	18,172	100.0%			
Gender	24	0.1	Female	5887	32.4%	5864	207	3.5%
			Male	12,266	67.6%	12,197	842	6.9%
			Total	18,153	100.0%			
Incident location	51	0.3	Other Location	5394	29.8%	5342	632	11.8%
			Home Location	12,732	70.2%	12,689	413	3.3%
			Total	18,126	100.0%			
Mechanical CPR	1163	6.4	No Mechanical CPR	10,842	63.7%	10,781	750	7.0%
			Mechanical CPR Provided	6172	36.3%	6145	228	3.7%
			Total	17,014	100.0%			
Season	0	0.0	Other	8582	47.2%	8532	563	6.6%
			Winter	9595	52.8%	9548	486	5.1%
			Total	18,177	100.0%			
First Shock Delivered By	59	0.3	Not Applicable	12,367	68.3%	12,328	121	1.0%
			Bystander Defibrillation	1235	6.8%	1225	367	30.0%
			EMS Defibrillation	4516	24.9%	4468	553	12.4%
			Total	18,118	100.0%			
Shockable Initial Rhythm	36	0.2	Non-Shockable	14,365	79.2%	14,316	154	1.1%
			Shockable	3776	20.8%	3728	895	24.0%
			Total	18,141	100.0%			
Chest Compressions Started By	304	1.7	EMS initiated CPR	4106	23.0%	4081	120	2.9%
			Bystander CPR	13,767	77.0%	13,700	915	6.7%
			Total	17,873	100.0%			
Time of Day	27	0.1	Night	3903	21.5%	3886	156	4.0%
			Evening	6524	35.9%	6489	410	6.3%
			Morning	7723	42.6%	7678	483	6.3%
			Total	18,150	100.0%			
Who Witnessed Collapse	0	0.0	Not Witnessed	8121	44.7%	8087	115	1.4%
			Bystander Witnessed	10,056	55.3%	9993	934	9.3%
			Total	18,177	100.0%			
Urban or Rural	643	3.5	Rural Location	6030	34.4%	6021	239	4.0%
			Urban Location	11,504	65.6%	11,425	754	6.6%
			Total	17,534	100.0%			
Weekday or Weekend	0	0.0	Weekend	5553	30.5%	5516	306	5.5%
			Weekday	12,624	69.5%	12,564	743	5.9%
			Total	18,177	100.0%			
Amiodarone Administered	32	0.2	No Amiodarone	16,244	89.5%	16,170	851	5.3%
			Amiodarone Administered	1901	10.5%	1879	195	10.4%
			Total	18,145	100.0%			
Transition Period (2015 & 2016)	0	0.0	Transition Period	4088	22.5%	4073	241	5.9%
			Other	14,089	77.5%	14,007	808	5.8%
			Total	18,177	100.0%			
Post Transition (2017–2020)	0	0.0	Post Transition Period	8931	49.1%	8900	527	5.9%
			Other	9246	50.9%	9180	522	5.7%
			Total	18,177	100.0%			
COVID Period (2020)	0	0.0	COVID Period	2320	12.8%	2312	123	5.3%
			Other	15,857	87.2%	15,768	926	5.9%
			Total	18,177	100.0%			

Table 1b – Resuscitation for out-of- hospital cardiac arrest in Ireland 2012–2020: Summary of continuous variables, missing data and survival.

Variable	Available Cases	Missing		All		Survivors		Non-Survivors	
		n	%	Mean *Median*	SD *IQR*	Mean *Median*	SD *IQR*	Mean *Median*	SD *IQR*
Age (Years)	17,928	249	1.4	63.2	19.7	56.8	16.8	63.7	19.8
				67	*52.0–78.0*	*59*	*46.0–68.0*	*68*	*53.0–78.0*
Call Response (Mins)	17,755	422	2.3	15.1	9.5	12.6	9.5	15.3	9.5
				13	*8.0–20.0*	*10*	*7.0–15.0*	*13*	*8.0–20.0*
Shocks Delivered	17,847	330	1.8	1.2	2.8	2.7	2.6	1.2	2.8
				0	*0.0–1.0*	*2*	*1.0–4.0*	*0*	*0.0–1.0*
Adrenaline Doses	18,088	89	0.5	2.9	2.7	1	1.7	3	2.7
				3	*0.0–5.0*	*0*	*0.0–1.0*	*3*	*0.0–5.0*

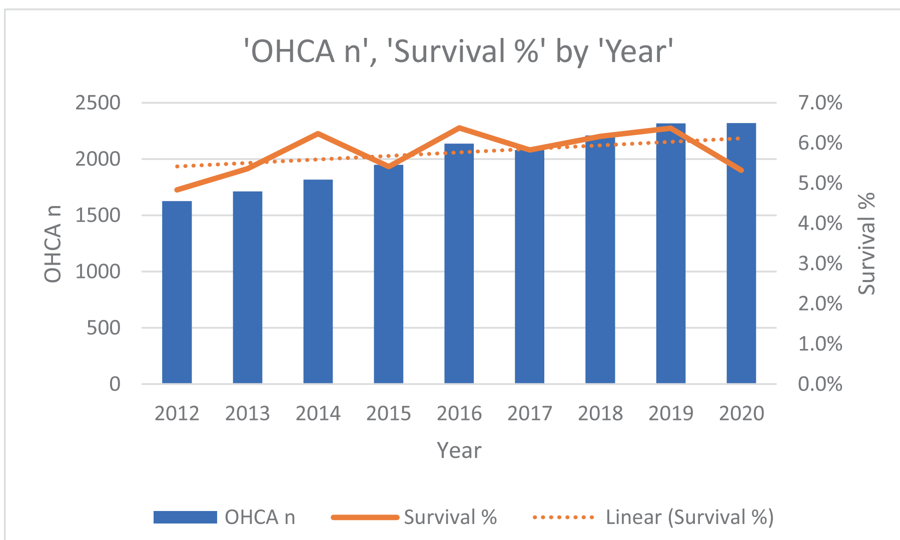

Fig. 1 – Resuscitation for out-of- hospital cardiac arrest in Ireland 2012–2020: Incidence & Survival over time.

ated with excessively wide confidence intervals. This suggests that the centralisation of EMS control on its own was not the principal driver of survival improvement over the time period. The COVID period variable was included in the final model and associated with decreased survival. The variables incident location, who witnessed collapse, chest compressions started by, shockable initial rhythm, first shock delivered by, total number of shocks, airway management, mechanical CPR and the number of adrenaline doses were all involved in pairwise interactions in the final model. The research excluded EMS witnessed OHCA, but beyond this took a whole OHCA population approach. In this context it is not surprising that including pairwise interactions in the final model improved fit. Cardiac arrest is not a specific diagnostic condition but rather a final common pathway in a range of different pathologic entities. The population captured in OHCAR was thus heterogenous in terms of the aetiology and circumstances of each OHCA event. Previous research has sought to limit such heterogeneity by focusing on the Utstein comparator sub-group (bystander witnessed and shockable initial rhythm) although even with this approach there may be unmeasured confounders.[27–29] In Ireland, the Utstein comparator sub-group is a minority of all OHCA cases (approximately 15%),[2] and EMS must ultimately provide care for all OHCA patients. While an ongoing focus on patients with shockable rhythms continues to be important given the potential for increased survival, the proportion of patients presenting with initial shockable rhythms has declined over time.[30,31] A key implication is the need to identify and study additional comparator subgroups beyond the sentinel Utstein comparator group. Further interrogation of the OHCAR dataset using the models derived in this study may help identify additional important comparator subgroups going forward.

Beyond those predictors in the final model that were involved in pairwise interactions, several other predictors are relevant to the aims of this study. Amiodarone administered had an odds ratio of 3.91 (95% CI 2.80, 5.48) in the final model, highlighting its importance in the subgroup of patients for whom its administration is indicated. Randomised controlled trial evidence has demonstrated that amiodarone can increase survival to hospital admission in patients with refractory shockable rhythms and may increase survival to hospital discharge in the sub-group with bystander witnessed cardiac arrest.[32] Resuscitation guidelines thus advocate its administration in relevant circumstances.[33] Currently in the Irish context, only advanced paramedics can administer intravascular medications

Table 2 – Resuscitation for out-of- hospital cardiac arrest in Ireland 2012–2020: Multivariable analysis, Final Model with Interactions – Complete Cases and Multiple Imputation.

Predictor	Involved in Interactions	Complete Cases		Multiple Imputation	
		Odds Ratio (95% Confidence Interval)	*p*-value	Odds Ratio (95% Confidence Interval)	*p*-value
Supraglottic Airway Device	*	2.58 (1.32, 5.02)	0.005	2.03 (1.10, 3.71)	0.023
Intubation	*	4.70 (1.97, 10.77)	<0.001	3.78 (1.80, 7.92)	<0.001
Age (years)		0.964 (0.959, 0.969)	<0.001	0.97 (0.96, 0.97)	<0.001
Male		1.23 (0.97, 1.56)	0.089	1.19 (0.97, 1.46)	0.103
Call Response Interval (minutes)		0.972 (0.959, 0.985)	<0.001	0.971 (0.960, 0.982)	<0.001
Home Location	*	0.36 (0.25, 0.52)	<0.001	0.36 (0.26, 0.51)	<0.001
Mechanical CPR Provided	*	0.43 (0.31,0.60)	<0.001	0.47 (0.35 0.64)	<0.001
Year		1.14 (1.08, 1.20)	<0.001	1.12 (1.08, 1.18)	<0.001
Bystander Defibrillation	*	19.67 (11.08, 35.05)	<0.001	16.60 (9.95, 27.68)	<0.001
EMS Defibrillation	*	9.23 (5.50, 15.49)	<0.001	8.16 (5.15, 12.92)	<0.001
Shockable Initial Rhythm	*	5.59 (3.65, 8.73)	<0.001	6.89 (4.69, 10.12)	<0.001
Bystander CPR	*	0.89 (0.50, 1.60)	0.679	0.82 (0.48, 1.38)	0.451
Total No of Shocks Delivered	*	0.89 (0.83, 0.95)	<0.001	0.89 (0.84, 0.94)	<0.001
Bystander Witnessed	*	1.19 (0.72, 1.99)	0.496	1.44 (0.92, 2.26)	0.114
Urban Location		1.40 (1.12, 1.77)	0.004	1.43 (1.16, 1.76)	0.001
Weekday		1.23 (0.99, 1.52)	0.052	1.24 (1.03, 1.48)	0.022
Number of Adrenaline Doses	*	0.62 (0.53, 0.70)	<0.001	0.64 (0.57, 0.72)	<0.001
Amiodarone Administered		3.91(2.80, 5.48)	<0.001	3.60 (2.68, 4.85)	<0.001
Covid Period (2020)		0.61(0.43, 0.87)	0.007	0.75 (0.55, 1.03)	0.073
Interacting Variables					
Supraglottic Airway Device * Bystander Defibrillation		0.27 (0.13, 0.56)	0.001	0.28 (0.14, 0.54)	<0.001
Intubation * Bystander Defibrillation		0.08 (0.03, 0.21)	<0.001	0.11 (0.05, 0.28)	<0.001
Supraglottic Airway Device * EMS Defibrillation		0.44 (0.23, 0.83)	0.001	0.43 (0.24, 0.76)	0.004
Intubation * EMS Defibrillation		0.25 (0.11, 0.58)	0.001	0.26 (0.13, 0.55)	<0.001
Supraglottic Airway Device * Total No of Shocks Delivered		1.11 (1.03, 1.21)	0.009	1.11(1.03, 1.19)	0.007
Intubation * Total No of Shocks Delivered		1.06 (0.95, 1.17)	0.332	1.07(0.98, 1.18)	0.149
Bystander Defibrillation * Number of Adrenaline Doses		0.69 (0.57, 0.83)	<0.001	0.68 (0.58, 0.80)	<0.001
EMS Defibrillation * Number of Adrenaline Doses		0.82 (0.71, 0.95)	0.008	0.81(0.71, 0.93)	0.002
Bystander CPR * Bystander Witnessed		3.32 (1.84, 5.92)	<0.001	3.00 (1.78, 5.04)	<0.001
Mechanical CPR Provided * Number of Adrenaline Doses		1.23 (1.11, 1.37)	<0.001	1.19(1.08, 1.31)	<0.001
Supraglottic Airway Device * Bystander CPR		0.42 (0.23, 0.76)	0.004	0.56 (0.33, 0.96)	0.035
Intubation * Bystander CPR		0.44 (0.21, 0.98)	0.038	0.54(0.28, 1.05)	0.068
Home Location * Shockable Initial Rhythm		1.85 (1.20, 2.85)	0.005	1.63 (1.10, 2.39)	0.014

and not all EMS resources that respond to OHCA are crewed by advanced paramedics. Thus, whether and how amiodarone can be made available to all OHCA patients that could benefit in Ireland should be further explored.

In the final model urban location was associated with increased odds of survival (OR 1.40, 95% CI 1.12, 1.77) when compared to rural location. This finding is in keeping with previous research carried out both in Ireland and internationally.[21,34] In the context of a final model that adjusts for the key elements of early community and EMS care this is an important finding. Over one third of all patients had OHCA in a rural setting and thus the survival differential is a significant issue at population level. The reasons for this survival differential are not clear. One issue that could be explored in follow up research is whether reduced rural access to specialist OHCA treatments is a driver of outcomes. When the final model effect estimates for weekday (OR 1.23, 95% CI 1.00, 1.52) and male sex (OR 1.23, 95% CI 0.97, 1.56) are inspected, both demonstrate effect estimates suggestive of increased survival, albeit with uncertainty in terms of confidence intervals. In sensitivity analysis weekday was associated with increased odds of survival (OR 1.24, 95% CI 1.03, 1.48). Over 30% of all OHCA in this study occurred at the weekend. Thus, consideration needs to be given to whether there could be a 'weekend' effect in terms of OHCA survival in Ireland. Previous research has demonstrated that this is of concern elsewhere.[35] Call

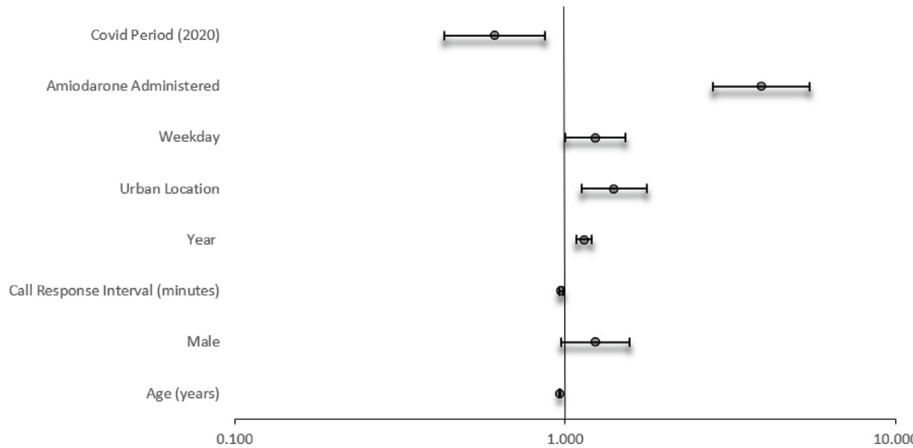

Fig. 2a – Resuscitation for out-of- hospital cardiac arrest in Ireland 2012–2020: Multivariable analysis, Final model – Predictors without Interactions (odds ratios & 95% confidence intervals).

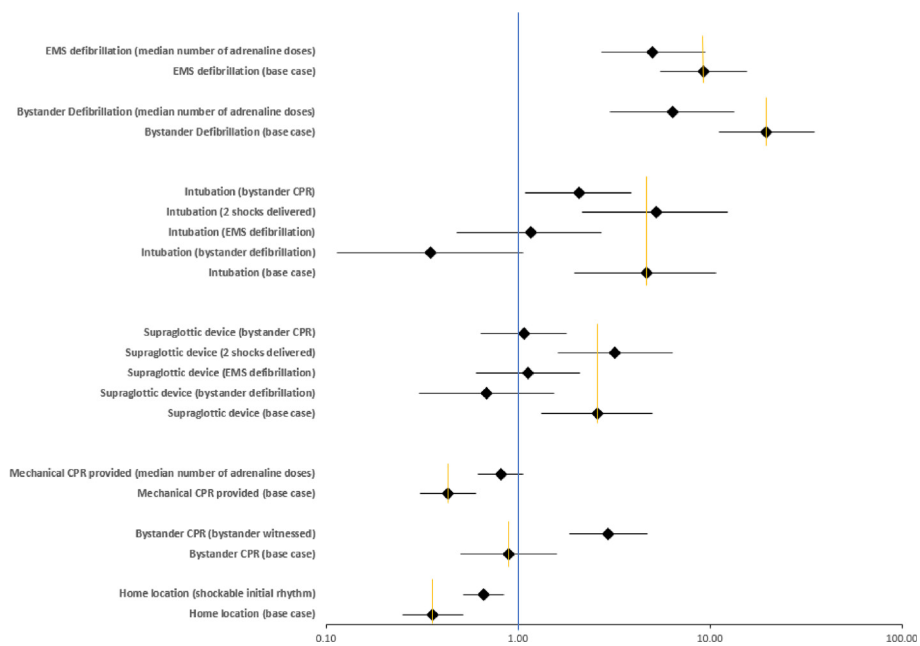

Fig. 2b – Resuscitation for out-of- hospital cardiac arrest in Ireland 2012–2020: Multivariable analysis, Final model predictors with interactions (odds ratio & 95% confidence intervals).

response interval as measured in minutes was associated with a decreased odds of survival in the final model, with an odds ratio of 0.97 (95% CI 0.96, 0.99) thus warranting ongoing consideration. It is important to consider though that the final model adjusted for both bystander CPR & defibrillation which may explain why the change in odds is modest for this predictor.

Although the centralisation of EMS control was not found to be a principal driver of survival improvement over the time period, it is important to note that other significant predictors incorporated in the final model could have been both related to the centralisation of EMS control and to survival. One such important variable is bystander CPR. The relationship between bystander CPR, the centralisation of EMS control (incorporating comprehensive introduction of dispatch assisted CPR) and other relevant variables such as call response interval will be specifically explored in follow up research. It is possible that bystander CPR which remained in the final model, may be a mediator of the transition, and so as a more proximate cause of any improvement in mortality it exceeded the transition effect. Thus, in future work we plan to investigate predictors of bystander CPR, including the transition period, to further explore this hypothesis. Given that this current modelling exercise considered OHCA at population level, it is also possible that the effects of bystander CPR (or other improvements that could be related to the centralisation of EMS control) on survival are diluted out, as only a subset of the overall OHCA population have the potential at the point of initial OHCA resuscitation care to be responsive to these measures. In this context, follow up subgroup analysis may be particularly important. It is notable that in the final model the predictor year had an odds ratio of 1.14 (95% CI 1.08, 1.20). This suggests that after adjusting for other important variables, the odds of survival increased on average by 14% year on year. The centralisation of EMS control in 2015 and 2016 was itself a component of a wider quality improvement programme that continued throughout the period of the study. This programme incorporated community interaction and public education, call taking and dispatch, quality care on scene, data management and audit.[4] Our final model suggests that a series of incremental developments rather than a single turning point event drove improved survival over the period. Importantly though, the final model demonstrated that the COVID period in 2020 was associated with decreased odds of survival (OR 0.61 95%CI 0.43, 0.87). The model adjusted for variables that capture key elements of bystander and EMS OHCA care known to have been disrupted by the COVID pandemic.[7,8] This raises the issue of whether disrupted preventative or hospital based care, or indeed pathologic factors inherent to COVID-19 were also drivers of decreased survival.[8] The effect of the COVID-19 pandemic will be considered in more detail in follow up research.

This research has a number of limitations that must be considered when interpreting its findings. The research is observational in nature and cannot definitively establish whether any of the predictors directly influenced survival. Our modelling strategy undertook a statistically driven approach to variable selection and interaction inclusion. Going forward, follow up analysis focusing on key subgroups and informed by clinically important elements of OHCA care will be undertaken. We acknowledge the limitations of stepwise variable selection and recognise the possibility that effect sizes may be inflated, and *p*-values too liberal. We thus have not made claims of effect based on statistical significance and have interpreted the effect sizes and confidence intervals with a degree of caution. In this initial research exercise, we have undertaken a high level, exploratory statistical analysis approach to OHCA registry data in Ireland, by including all causes and all ages. Follow up research will consider clinically important subgroups and the interaction of clinically relevant OHCAR variables in greater detail. Utstein variables are known to explain only 51% of the variation in OHCA survival following OHCA, thus much of the variability in OHCA survival in Ireland and elsewhere is yet to be explained.[36] OHCAR captures many key elements of the OHCA care provided by bystanders and by EMS, however it does not capture patient level information related to pre-event health status or comorbid conditions. Neither does it capture the nature and content of the hospital-based care provided to OHCA patients. It is likely that such information that is not currently captured by OHCAR is relevant to OHCA outcome. Follow up research should aim to incorporate patient level health status and hospital care variables in an effort to enhance the scientific understanding of the variation in survival following OHCA.[27]

Conclusions

At population level in Ireland OHCA is a complex issue that effects heterogenous groups of patients. From 2012 to 2020 most OHCA survivors had shockable initial rhythms and the highest overall survival (30%) was seen in patients who had defibrillation before EMS arrival. Given the known impact of bystander defibrillation, Ireland should continue to explore how this can be increased. In tandem it is important to identify and study other key OHCA patient subgroups in future. Even when important covariates were adjusted for it was apparent that OHCA survival has increased incrementally in Ireland over the period 2012–2020. The COVID pandemic was however independently associated with decreased odds of OHCA survival. This was true even after accounting for disruption to key elements of bystander and EMS care. Urban location was associated with both unadjusted and adjusted increased odds of survival. More research is needed to understand the drivers of this urban – rural gap. Finally, this work highlights the research and development contributions which a national OHCAR register can provide over an extended period.

CRediT authorship contribution statement

Tomás Barry: Writing – review & editing, Writing – original draft, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Alice Kasemiire:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis. **Martin Quinn:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Conor Deasy:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Gerard Bury:** Writing – review & editing, Methodology, Investigation, Conceptualization. **Siobhan Masterson:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Ricardo Segurado:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Formal analysis. **Andrew W Murphy:** Writing – review & editing, Writing – original draft, Resources, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: 'TB has research, clinical and educational roles in resuscitation care. He is a member of the Pre-Hospital Emergency Care Council (Ireland). All authors declare no conflict of interest.'.

Acknowledgements

TB acknowledges funding support from the Health Research Board (CSF-2020-006).

AWM acknowledges funding support from the National Ambulance Service.

The authors acknowledge the assistance of colleagues from the National Ambulance Service and Irish Heart Foundation who assisted the study team in ensuring a comprehensive understanding of relevant health system developments pertinent to OHCA care over this study's time period of concern.

The authors also wish to acknowledge all current and previous members of the OHCAR Steering Group, first chaired by Dr Peter Wright in 2007.

Appendix A. Supplementary material

Supplementary material to this article can be found online at https://doi.org/10.1016/j.resplu.2024.100641.

Author details

on behalf of the Out-of-Hospital Cardiac Arrest Registry Steering Group [a]School of Medicine, University College Dublin, Ireland[b]UCD Centre for Support and Training in Analysis and Research, School of Public Health, Physiotherapy and Sports Science, University College Dublin, Dublin, Ireland[c]National Ambulance Service, Health Services Executive, Ireland [d]School of Medicine, University College Cork, Cork, Ireland[e]University College Dublin, Ireland[f]Clinical Strategy and Evaluation' Health Services Executive, National Ambulance Service, Ireland[g]Discipline of General Practice, University of Galway, Galway, Ireland

REFERENCES

1. CSO. Census of Population 2022 – Summary Results 2023 [cited 2023 13/07/2023]. Available from: https://www.cso.ie/en/statistics/population/censusofpopulation2022/censusofpopulation2022-summaryresults/.
2. OHCAR. National ambulance service, out-of-hospital cardiac arrest register, annual report 2021. 2022.
3. HSE. Out of Hospital Cardiac Arrest Register (OHCAR) 2023 [cited 2023 13/07/2023]. Available from: https://www.hse.ie/eng/services/news/newsfeatures/out-of-hospital-cardiac-arrest-register-ohcar-/.
4. Barry T, Kasemiire A, Quinn M, et al. Outcomes of out-of-hospital cardiac arrest in Ireland 2012–2020: Protocol for an observational study. HRB Open Res 2023;6:17.
5. Conway R, Kelly DM, Mullane P, et al. Epidemiology of COVID-19 and public health restrictions during the first wave of the pandemic in Ireland in 2020. J Public Health (Oxf) 2021;43:714–22.
6. Heffernan E, Keegan D, Clarke B, et al. Quality improvement in a crisis: a qualitative study of experiences and lessons learned from the Irish National Ambulance Service response to the COVID-19 pandemic. BMJ Open 2022;12:e057162.
7. Scquizzato T, D'Amico F, Rocchi M, et al. Impact of COVID-19 pandemic on out-of-hospital cardiac arrest system-of-care: A systematic review and meta-analysis. Prehosp Emerg Care: Off J Natl Assoc EMS Physicians Natl Assoc State EMS Directors. 2021:1–12.
8. Teoh SE, Masuda Y, Tan DJH, et al. Impact of the COVID-19 pandemic on the epidemiology of out-of-hospital cardiac arrest: a systematic review and meta-analysis. Ann Intensive Care 2021;11.
9. Sasson C, Rogers MA, Dahl J, Kellermann AL. Predictors of survival from out-of-hospital cardiac arrest: a systematic review and meta-analysis. Circ Cardiovasc Qual Outcomes 2010;3:63–81.
10. Martinell L, Nielsen N, Herlitz J, et al. Early predictors of poor outcome after out-of-hospital cardiac arrest. Crit Care 2017;21:96.
11. Barry T, Gonzalez A, Conroy N, et al. Mapping the potential of community first responders to increase cardiac arrest survival. 2018.
12. PHECC. Pre-Hospital Emergency Care Council; What We Do 2021 [Available from: https://www.phecit.ie/PHECC/What_we_do/PHECC/What_we_do/What_we_do.aspx?hkey=ad21b38b-ae2b-4bf4-85da-9e0abecde29f.
13. PHECC. Clinical Practice Guidelines, Advanced Paramedic. Kildare; 2021.
14. HSE. Urgent and Emergency Care 2023 [13/07/2023]. Available from: https://www.hse.ie/eng/about/who/acute-hospitals-division/patient-care/emergency-care/.
15. Jacobs I, Nadkarni V, Bahr J, et al. Cardiac arrest and cardiopulmonary resuscitation outcome reports: update and simplification of the Utstein templates for resuscitation registries. Resuscitation 2004;63:233–49.
16. Gräsner J-T, Wnent J, Herlitz J, et al. Survival after out-of-hospital cardiac arrest in Europe – Results of the EuReCa TWO study. Resuscitation 2020;148:218–26.
17. Nishiyama C, Kiguchi T, Okubo M, et al. Three-year trends in out-of-hospital cardiac arrest across the world: Second report from the International Liaison Committee on Resuscitation (ILCOR). Resuscitation 2023;186 109757.
18. Gräsner JT, Lefering R, Koster RW, et al. EuReCa ONE-27 Nations, ONE Europe, ONE Registry: A prospective one month analysis of out-of-hospital cardiac arrest outcomes in 27 countries in Europe. Resuscitation 2016;105:188–95.
19. Moran PS, Teljeur C, Masterson S, O'Neill M, Harrington P, Ryan M. Cost-effectiveness of a national public access defibrillation programme. Resuscitation 2015;91:48–55.
20. Masterson S, Teljeur C, Cullinan J, Murphy AW, Deasy C, Vellinga A. Out-of-hospital cardiac arrest in the home: Can area characteristics identify at-risk communities in the Republic of Ireland? Int J Health Geogr 2018;17:6.
21. Masterson S, Wright P, O'Donnell C, et al. Urban and rural differences in out-of-hospital cardiac arrest in Ireland. Resuscitation 2015;91:42–7.
22. Barry T, Conroy N, Headon M, et al. The MERIT 3 project: Alerting general practitioners to cardiac arrest in the community. Resuscitation 2017;121:141–6.
23. Barry T, Headon M, Quinn M, et al. General practice and cardiac arrest community first response in Ireland. Resusc Plus 2021;6:100127.
24. Tanner R, Masterson S, Galvin J, et al. Out-of-hospital cardiac arrests in the young population; a 6-year review of the Irish out-of-hospital cardiac arrest register. Postgrad Med J 2021;97:280–5.
25. Tanner R, Masterson S, Jensen M, et al. Out-of-hospital cardiac arrests in the older population in Ireland. Emerg Med J 2017;34:659–64.
26. Nolan JP, Maconochie I, Soar J, et al. Executive summary: 2020 international consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendations. Circulation 2020;142(16_suppl_1):S2–S27.
27. Perkins GD, Jacobs IG, Nadkarni VM, et al. Cardiac Arrest and Cardiopulmonary Resuscitation Outcome Reports: Update of the Utstein Resuscitation Registry Templates for Out-of-Hospital Cardiac Arrest A Statement for Healthcare Professionals From a Task Force of the International Liaison Committee on Resuscitation (American Heart Association, European Resuscitation Council, Australian and New Zealand Council on Resuscitation, Heart and Stroke Foundation of Canada, InterAmerican Heart Foundation, Resuscitation Council of Southern Africa, Re. Circulation 2015;132:1286–300.
28. Kiguchi T, Okubo M, Nishiyama C, et al. Out-of-hospital cardiac arrest across the World: First report from the International Liaison Committee on Resuscitation (ILCOR). Resuscitation 2020;152:39–49.
29. Dumas F, Blackwood J, White L, et al. The relationship between chronic health conditions and outcome following out-of-hospital ventricular fibrillation cardiac arrest. Resuscitation 2017;120:71–6.
30. Oving I, de Graaf C, Karlsson L, et al. Occurrence of shockable rhythm in out-of-hospital cardiac arrest over time: A report from the COSTA group. Resuscitation 2020;151:67–74.
31. Cobb LA, Fahrenbruch CE, Olsufka M, Copass MK. Changing incidence of out-of-hospital ventricular fibrillation, 1980–2000. JAMA 2002;288:3008–13.
32. Kudenchuk PJ, Brown SP, Daya M, et al. Amiodarone, lidocaine, or placebo in out-of-hospital cardiac arrest. N Engl J Med 2016;374:1711–22.
33. Soar J, Böttiger BW, Carli P, et al. European Resuscitation Council Guidelines 2021: Adult advanced life support. Resuscitation 2021;161:115–51.
34. Smith A, Masters S, Ball S, Finn J. The incidence and outcomes of out-of-hospital cardiac arrest in metropolitan versus rural locations: A

systematic review and meta-analysis. Resuscitation 2023;185 109655.
35. El Asmar A, Dakessian A, Bachir R, El Sayed M. Out of hospital cardiac arrest outcomes: Impact of weekdays vs weekends admission on survival to hospital discharge. Resuscitation 2019;143:29–34.
36. Dyson K, Brown SP, May S, et al. International variation in survival after out-of-hospital cardiac arrest: A validation study of the Utstein template. Resuscitation 2019;138:168–81.