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The impact of resuscitation system factors on in-hospital cardiac arrest outcomes across UK hospitals: an observational study

Keith Couper^{1,2}, Alexina J Mason³, Doug Gould³, Jerry P. Nolan^{1,4}, Jasmeet Soar⁵, Joyce Yeung^{1,2}, David Harrison³, Gavin D Perkins^{1,2}

- 1) Warwick Clinical Trials Unit, Warwick Medical School, University of Warwick, Coventry, UK
- 2) Critical Care Unit, Birmingham Heartlands Hospital, University Hospitals Birmingham NHS Foundation Trust, Birmingham, UK
- 3) Intensive Care National Audit & Research Centre, London, UK
- 4) Critical Care Unit, Royal United Hospital, Royal United Hospitals Bath NHS Trust, Bath, UK
- 5) Critical Care Unit, Southmead Hospital, North Bristol NHS Trust, Bristol , UK

Corresponding author:

Professor Gavin Perkins

Warwick Clinical Trials Unit, Warwick Medical School, University of Warwick, Coventry, UK.

Email: g.d.perkins@warwick.ac.uk

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Abstract

Purpose of the study

To explore whether variation in in-hospital cardiac arrest (IHCA) survival can be explained by differences in resuscitation service provision across UK acute hospitals.

Methods

We linked information on key clinical practices with patient data of adults who had a cardiac arrest on a general hospital ward or emergency admissions unit in 2016/17. We used multi-level Bayesian models to explore associations between system quality indicators (number of resuscitation officers, audits time to first shock, review unexpected non-survivors, arrest team meets at handover, hot debrief, cold debrief, real-time audio-visual feedback, frequency of mock arrest provision) and adjusted hospital survival.

Results

We received survey responses from 110 out of 180 eligible hospitals (response rate 61%) relating to 12285 cardiac arrest cases. Variation across trusts was observed in the number of resuscitation officers (median 0.7 (interquartile range 0.5, 0.9) per 750 clinical staff employed. Key system quality indicators were undertaken infrequently: audit of time to first shock (44.7%), arrest team meeting at handover (28.9%), mock arrests \geq monthly (22.4%), and use of CPR feedback devices (18.4%). The probability that the system quality indicators had a positive effect on hospital survival ranged from 10% to 89%. However, there was uncertainty in the estimated odds ratios and we cannot exclude the possibility of a clinical benefit. Findings were consistent across secondary outcomes.

Conclusion

In this study, we identified variation in implementation of system quality indicators. Amongst hospitals that responded to our survey, the probability that individual factors increase the odds of hospital survival ranges from 10 to 89%..

Introduction

Variability in outcome following cardiac arrest has been reported between geographical area, Emergency Medical Service (EMS) system, hospital and country.[1-4] For out-of-hospital cardiac arrest, strategies to optimise outcome and reduce variability have typically focussed on public health initiatives to optimise bystander cardiopulmonary resuscitation (CPR) and public access defibrillator use, and EMS response to cardiac arrest.[5, 6]

In contrast, for in-hospital cardiac arrest, strategies to optimise outcome and reduce outcome variability have typically focussed on strategies to improve CPR quality and system response to cardiac arrest. These strategies include studies of debriefing, rolling refreshers, training and multi-component quality improvement projects.[7-9] In the UK and other countries, there is variability in how these interventions have been implemented.[10-12] This may reflect resource availability or local uncertainty about the effectiveness of interventions.

The aim of this study was to explore the extent to which variability in outcome following in-hospital cardiac arrest could be explained by variation in system quality indicators.

Methods

In this observational study, we linked resuscitation service provision data with in-hospital cardiac arrest (IHCA) audit data from the National Cardiac Arrest Audit (NCAA) to explore the association between resuscitation system quality indicators and outcomes following in-hospital cardiac arrest.[13]

Context

In the UK, publicly funded hospitals are managed by National Health Service (NHS) trusts or boards (described here as NHS trusts). The number of hospitals managed by an individual NHS trust ranges from one to approximately six. In general, practice within hospitals is locally determined by an NHS trust-wide policy. However, specific characteristics of individual hospitals (for example, hospital size, and clinical specialty) within an NHS trust may demand some variation in practice.

Resuscitation officers are experienced health professionals with a specialist clinical interest in cardiac arrest, who lead resuscitation service provision at NHS trusts. The resuscitation officer role encompasses training, quality assurance, service improvement, research, and clinical care delivery. The Resuscitation Council (UK) has developed quality standards for UK hospital

resuscitation services which provides guidance on audit, standardised equipment, training, resuscitation team configuration audit and post event debriefing.[14]

Resuscitation system quality indicators

We used a survey to collect information on current implementation of resuscitation system quality indicators at participating hospitals. To develop the survey, study collaborators reviewed the wider literature, UK resuscitation guidelines, and UK resuscitation quality standards,[3, 14, 15] and selected areas where there was likely to be variability in practice. Our final survey comprised approximately 30 questions. Hospitals were eligible to complete the survey if they provided general acute services to adult in-patients and had submitted at least six-months data to NCAA between 1 January 2016 and 31 December 2017.

We initially distributed the survey by email to NCAA contacts at each NHS Trust. Respondents were asked to base responses on practice at the largest hospital, and provide free-text comments where practice at smaller hospitals differed. If there was no response to the original email, we followed up by email and phone. Where appropriate, initial contacts were invited to nominate a colleague to complete the survey.

The survey collected data on current hospital activity only. Survey completion was deemed as consent to participate. Additional Trust-level data on workforce were collected from Government data sources.

National Cardiac Arrest Audit (NCAA)

The NCAA, a collaboration between the Resuscitation Council (UK) and the Intensive Care National Audit and Research Centre, is a UK-wide audit of IHCA . NCAA collects data on all cardiac arrest events (defined as an individual in receipt of chest compressions and/or defibrillation) attended by hospital cardiac arrest teams in response to an emergency call.[13] NCAA collects data on patient demographics, cardiac arrest characteristics, and patient outcomes, based on standardised definitions. Hospital participation in NCAA is voluntary. Data are collected at the hospital level.

For this study, we included adult (≥ 16 years) patients who had an IHCA on a general hospital ward or emergency admissions unit between 1 January 2016 and 31 December 2017 at an eligible hospital that responded to our survey. We excluded second or subsequent cardiac arrests in the same patient, patients with missing outcome or predictor variable data, and patients with a do not attempt cardiopulmonary resuscitation (DNACPR) decision. NCAA is approved to collect and process identifiable patient data by the Health Research Authority Confidentiality Advisory Group (ECC 2-06(n)/2009) under section 251 of the NHS Act 2006.

Outcomes

Our primary outcome was survival to hospital discharge. Secondary outcomes were return of spontaneous circulation (ROSC) for greater than 20 minutes and favourable neurological outcome at hospital discharge, defined as a Cerebral Performance Category (CPC) score of 1 or 2.

Data analysis and modelling

Where there was variability between hospitals within a trust, we analysed survey responses at a hospital level. Otherwise, the analysis was carried out at the trust level. For descriptive analysis, we divided the eligible hospitals/trusts into quintiles based on their risk-adjusted survival rates.[16]

Following review of the survey data, but before any modelling, study collaborators identified eight quality indicators for inclusion in the Bayesian models. The study statistician provided expert advice on the number of variables appropriate to include in the model. The quality indicators selected were: number of resuscitation officers, hospital audits time to first shock, hospital reviews NCAA unexpected non-survivors, arrest team meets at handover, hot debrief, cold debrief, real-time audio-visual feedback, and frequency of mock arrest provision (regular/infrequent/none).

For modelling, we used a Bayesian hierarchical logistic regression model, adjusted for patient level and trust level confounders, to explore the association between outcomes and our pre-defined resuscitation system quality indicators. We report the posterior median and 95% credible interval of the odds ratio of hospital survival for each quality indicator, and the posterior probability that the quality indicator increases the odds of survival. We selected minimally informative priors for all unknown parameters, so no additional information was incorporated into the model. As a secondary analysis of the primary outcome, the risk adjusted survival rates were modelled for each trust using a Bayesian linear regression. Further details of the modelling strategy are included in the electronic supplement.

Results

In October 2017, there were 180 hospitals in NCAA across 128 trusts that were potentially eligible for the study (figure one). Between November 2017 and February 2018, we received survey responses from 110 hospitals (76 trusts), representing a hospital response rate of 61% and trust response rate of 59%. Patient characteristics from responding hospitals and non-responding hospitals were similar (electronic supplement).

Survey findings

The median number of beds by trust and hospital was 728 (interquartile range (IQR) 499, 991) and 496 (IQR 381, 694) respectively. Across responding NHS trust, the median number of clinical staff employed was 4000 (IQR 2902, 6000) and 3 (IQR 2, 4) whole-time equivalent Resuscitation Officers.

The provision of mock arrests was common (72 hospitals, 65%), but frequency was often low such that 67% (n=48) of these hospitals provided mock arrests three-monthly or less frequently. Fifty hospitals (45.5%) provided post-arrest debriefing, but this rarely incorporated data on CPR quality (n=7, 14%).

The most senior medical member of the cardiac arrest team was typically a registrar (n=105, 95%). Teams usually included a critical care or cardiology nurse (n=84, 76%) and a team member skilled in tracheal intubation (n=91, 83%). Primary percutaneous coronary intervention was available 24/7 at 27% (n=30) hospitals. Additional survey results for trusts and hospitals are included as tables one and two respectively. There was no clear trend between any variable and risk-adjusted survival.

Modelling

Across responding hospitals, there were 23,756 cardiac arrests over the study period, of which 12,852 occurred in patients aged 16 years or over on either a general hospital ward or emergency admissions unit. We subsequently excluded 567 patients (multiple reasons allowed) because of: second or subsequent cardiac arrests in the same patient (n=159), missing primary outcome or predictor variable data (n=5), and presence of a DNACPR decision (n=405). Neurological outcome data were missing for 117 (1%) patients.

Of the 12,285 eligible in-hospital cardiac arrest events, most patients were male (n=7081, 58%), had a cardiac arrest on a general ward (n=10718, 87%), and with an initial rhythm of pulseless electrical activity (n=6683, 54%). The mean age was 74.7 years (SD 13.6). In total, 5412 (44.1%) patients had ROSC, 1815 (14.8%) survived to hospital discharge, and 1613 (13.3%) survived to hospital discharge with good neurological outcome (table three).

We observed marked variability in risk-adjusted survival across trusts, with a three-fold difference between the lowest and highest-performing trusts. Figure two depicts this variability for an example patient.

Across our pre-defined eight resuscitation service factors, the probability of being associated with a positive effect on hospital survival did not exceed 90%. Figure three shows the full posterior distribution of each odds ratio as a density strip on the log scale, where the darkness at a point is proportional to the probability density.[17] For example, there is an 81% probability that an additional resuscitation officer for every 750 clinical staff increases the odds of hospital survival, with an odds ratio of 1.15 (95% credible interval 0.84 to 1.56). Across all factors, we observed considerable uncertainty in the estimated odds ratios and a clinical benefit cannot be excluded for any factor.

Results for our secondary outcomes of ROSC and survival to discharge with good neurological outcome were consistent with the findings of the analysis for our primary outcome (electronic supplement). Similarly, our secondary analysis of the primary outcome generated similar results to our main analysis (electronic supplement).

Discussion

In this observational study, we identified variability in practice and outcome across the 110 hospitals that participated in NCAA and responded to our survey. There was variation in the provision of resuscitation officers and other key indicators relating to resuscitation system quality. In our modelling, which linked hospital resuscitation service provision with data from 12,285 adult in-hospital cardiac arrest cases, we found that the probability did not exceed 90% that any of our pre-defined eight resuscitation system quality indicators is associated with hospital survival, or any of our secondary outcomes. However, there is uncertainty in our results such that we cannot rule out the possibility that any of these factors are associated with outcome.

Our finding that no system quality indicator was associated with patient outcome contrasts with an analysis of the American Heart Association Get With Guidelines-Resuscitation Registry (AHA GWTG-R) dataset by Chan and colleagues.[18] In that study, survey data from 130 hospitals were linked with registry data on in-hospital cardiac cases. Using a frequentist hierarchical proportional odds logistic regression model, the authors identified three practices associated with improved risk-standardised survival rates, namely monitoring for interruptions in chest compressions, reviewing cardiac arrest cases monthly or quarterly and presence of a resuscitation champion.

Direct comparison between our study and that of Chan is challenging because of differences in survey construction. Firstly, the survey by Chan et al was lengthier than our survey (45 questions on 22 resuscitation strategies) as we opted for a shorter survey with a view to

maximising response rate. Secondly, there were important differences in question phraseology between our studies, which reflect differences in local practice. For example, we asked about use of real-time audio-visual feedback and found no association with risk-adjusted survival; in contrast, Chan et al found an association between the tracking of 'unnecessary interruptions in chest compressions' and risk-standardised survival. In addition, the North American concept of a resuscitation champion does not equate to resuscitation officers in the UK context, which are standard across all NHS hospitals. Finally, the best performing hospitals in Chan's study, outperformed those in our study on key quality performance indicators, such as tracking time to defibrillation (89% versus 50%) and provision of mock codes (89% versus 69%). The limited uptake of these key quality indicators even in the best performing hospitals may in part explain the lack of impact on outcomes.

In another recent study, 158 clinical and administrative staff at nine hospitals that contributed data to the GWTG-R registry were interviewed in an attempt to determine how those hospitals achieving the highest survival rates for IHCA organised their resuscitation teams; the nine hospitals were selected to represent the top, middle and bottom quartiles of survival for IHCA.[19] Resuscitation teams at the top-performing hospitals had designated teams, included resuscitation team members from diverse disciplines, gave clear roles and responsibilities to team members, provided better communication and leadership during IHCA and participated in in-depth mock codes. In our survey, all participating hospitals had designated resuscitation teams, although only two-thirds of hospitals undertook mock codes and only one-third of teams pre-briefed by meeting at each handover. Our finding of practice variability across hospitals reflects the findings of previous surveys, both within the UK and internationally.[10-12]

Our study has several limitations. Firstly, linkage of patient data with survey data relied on hospitals both participating in NCAA and having sufficient historical data. Previous studies have found associations between cardiac arrest registry participation and quality of care, such that we cannot generalise our findings to non-NCAA hospitals.[20, 21] Secondly, we received survey responses from only 61% of the 180 NCAA participating hospitals that were contacted. Although, key hospital and patient-level characteristics from responding and non-responding hospitals were similar, we were unable to compare implementation of resuscitation quality indicators between responding and non-responding hospitals. It is possible that responding hospitals were not representative of all 180 hospitals. Thirdly, we relied on single NCAA contacts at each hospital to answer the survey questions and their perception of the practice throughout their hospitals may not have been accurate. Fourthly, our survey did not collect data on how long key interventions had been implemented for or the quality of that implementation. This may dilute the reported effect of quality indicators. Finally, the limited scope of the NCAA dataset and the need for the study team to select a limited number of factors to investigate may mean there are residual system and patient-level confounders that are not accounted for in our modelling.

Further research is required so that we can understand which resuscitation services factors contribute to increased survival after IHCA. Prospective randomised trials will be challenging to deliver but some of these resuscitation service factors could potentially be studied using a stepped-wedge methodology.[22]

In conclusion, there was variation in adoption of key resuscitation system quality indicators amongst our cohort of 110 UK hospitals. Amongst the 61% of hospitals that responded to the survey, the probability that any individual factor increases the odds of hospital survival ranges from 10 to 89%.

Conflicts of interest:

JN, JS and GDP are editors of Resuscitation. JN chairs the NCAA steering group. KC, AM, DG, JY, DH have no conflicts of interest.

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Legends for Figures

Figure 1: Flow chart of participation in resuscitation service survey

Figure 2: Variability in outcome across hospitals

(Figure footnote: *- For a 78 year old male patient who arrested on a general hospital ward, with prior length of stay 2-7 days, medical reason for admission, non-shockable PEA presenting rhythm and not deteriorating at team arrival.

Figure 3: Odds ratios of hospital survival for the pre-specified resuscitation quality indicators

(Figure footnote: the full posterior distribution of each odds ratio is also shown as a density strip on the log scale, where the darkness at a point is proportional to the probability density. Values greater than 1 indicate that the RSP factor has a positive effect on hospital survival.)

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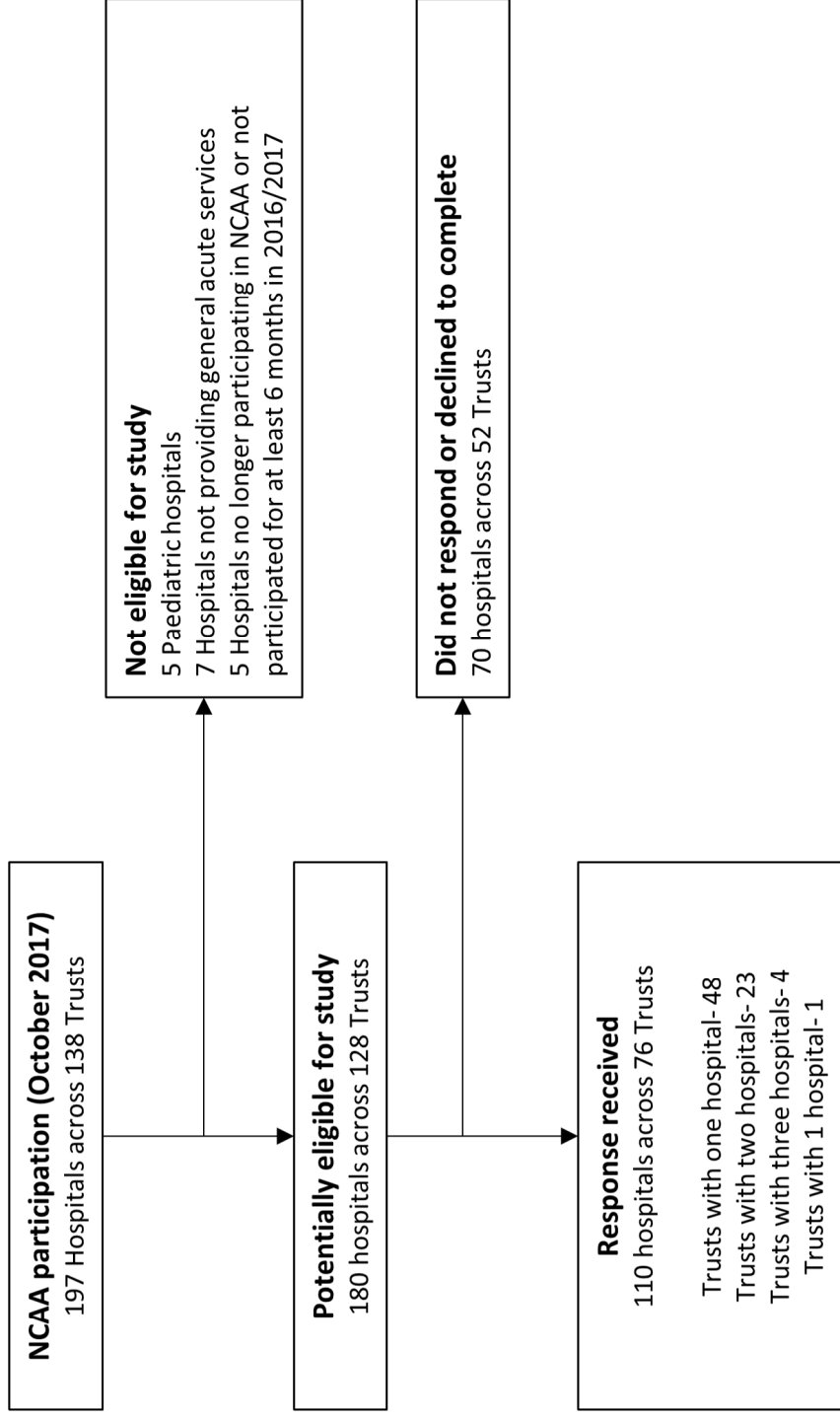
Table one: Survey responses by Trust

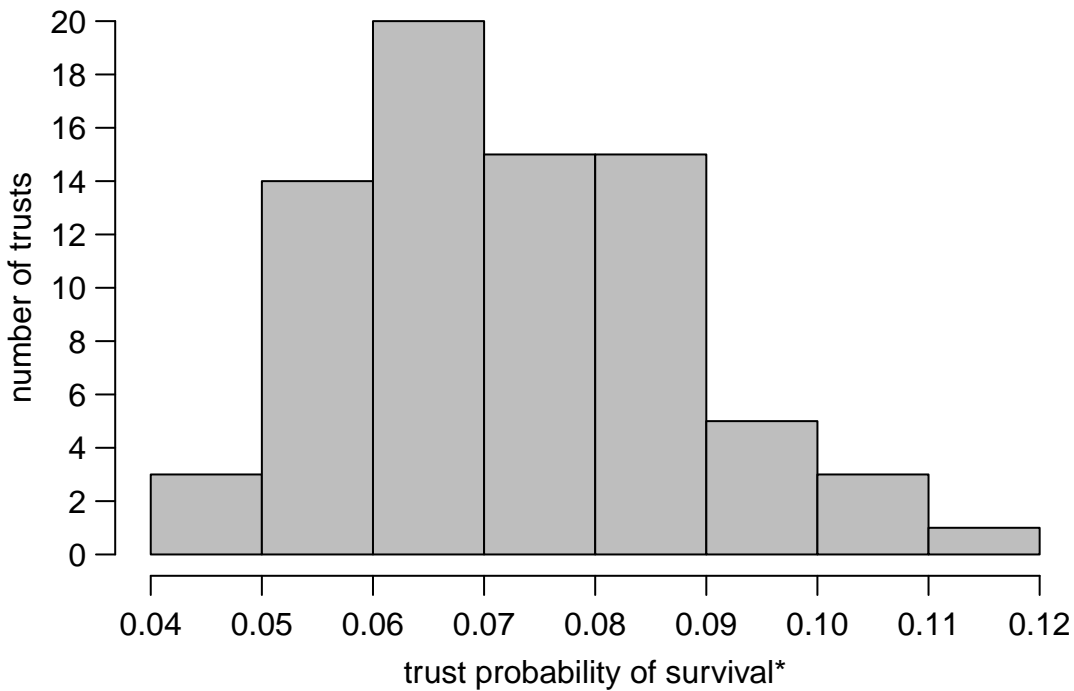
	Quintile‡					Total (n=76)
	Lowest (n=15)	Second (n=15)	Third (n=15)	Forth (n=15)	Fifth (n=16)	
Clinical staff employed- median (lq,uq)†	2837 (1804,3837)	2904 (1924,3938)	2329 (2116,3198)	3329 (2570,5020)	4148 (2868,7092)	2945 (2178,4443)
WTE resuscitation officers- median (lq,uq)†	3 (2,3)	3 (2,4)	2 (2,3)	3 (2,4)	4 (3,5)	3 (2,4)
Standardised WTE resuscitation officers- median (lq,uq) †*	0.8 (0.6,0.9)	0.7 (0.4,0.9)	0.7 (0.6,0.9)	0.6 (0.5,0.8)	0.7 (0.5,0.9)	0.7 (0.5,0.9)
Staff compliance with resuscitation mandatory training (%)- median (lq,uq)†	78 (72,81)	85 (75,88)	84 (70,85)	82 (74,85)	82 (78,86)	82 (72,85)
Clinical staff with ILS (%)- median (lq,uq)†	10 (10,14)	50 (14,50)	18 (11,20)	14 (5,28)	14 (12,24)	16 (10,25)
Clinical staff with ALS (%)- median (lq,uq)†	10 (9,10)	7 (5,10)	8 (5,10)	6 (4,14)	10 (5,14)	10 (5,10)
Mock arrest provision- n(%)						
Weekly	0 (0)	1 (6.7)	0 (0)	3 (20.0)	0 (0)	4 (5.3)
Fortnightly	1 (6.7)	1 (6.7)	0 (0)	1 (6.7)	0 (0)	3 (3.9)
Monthly	2 (13.3)	3 (20.0)	0 (0)	2 (13.3)	3 (18.8)	10 (13.2)
Every three-months	1 (6.7)	2 (13.3)	0 (0)	1 (6.7)	4 (25.0)	8 (10.5)
Less than every three-months	2 (13.3)	6 (40.0)	7 (46.7)	5 (33.3)	4 (25.0)	24 (31.6)
Not provided	9 (60.0)	2 (13.3)	8 (53.3)	3 (20.0)	5 (31.2)	27 (35.5)
Arrest team meet at handover- n(%)	2 (13.3)	7 (46.7)	8 (53.3)	3 (20.0)	2 (12.5)	22 (28.9)
Type of debrief- n(%)*						
Hot debrief only	1 (6.7)	4 (26.7)	1 (6.7)	5 (33.3)	2 (12.5)	13 (17.1)
Cold debrief only	3 (20.0)	0 (0)	3 (20.0)	1 (6.7)	1 (6.2)	8 (10.5)
Hot and cold debrief	0 (0)	1 (6.7)	0 (0)	0 (0)	1 (6.2)	2 (2.6)
Cold and written debrief	0 (0)	0 (0)	1 (6.7)	0 (0)	0 (0)	1 (1.3)
No debrief	11 (73.3)	10 (66.7)	10 (66.7)	9 (60.0)	12 (75.0)	52 (68.4)
Debriefing includes CPR quality data- n(%)	0 (0)	0 (0)	3 (20.0)	2 (13.3)	1 (6.2)	6 (7.9)
Resuscitation equipment checking- n(%)						
Every shift/ 12-hours	2 (13.3)	2 (13.3)	1 (6.7)	1 (6.7)	0 (0)	6 (7.9)
Daily	11 (7.3)	13 (86.7)	13 (86.7)	14 (93.3)	13 (81.2)	64 (84.2)

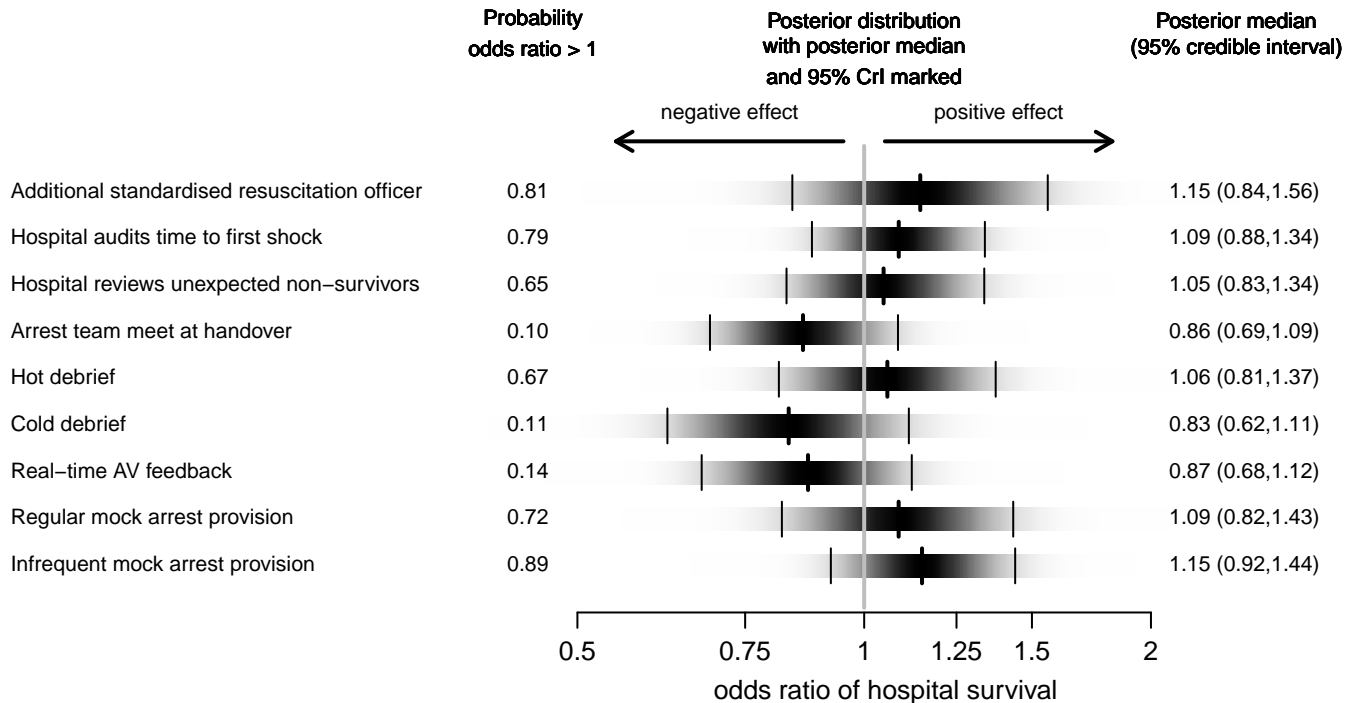
Table two: Survey responses by Hospital

		Quintile†					Total (n=110)
		Lowest (n=22)	Second (n=22)	Third (n=22)	Forth (n=22)	Fifth (n=22)	
Resuscitation officers attend cardiac arrests- n(%)							
	All arrests 24/7	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	All arrests in office hours	5 (22.7)	8 (36.4)	5 (22.7)	6 (27.3)	7 (31.8)	31 (28.2)
	Only when available	14 (63.6)	13 (59.1)	16 (72.7)	15 (68.2)	14 (63.6)	72 (65.5)
	None	3 (13.6)	1 (4.5)	1 (4.5)	1 (4.5)	1 (4.5)	7 (6.4)
Most senior medical arrest team member- n(%)							
	Consultant	0 (0)	1 (4.5)	1 (4.5)	0 (0)	0 (0)	2 (1.8)
	Registrar	22 (100)	20 (90.9)	21 (95.5)	21 (95.5)	21 (5.5)	105 (95.5)
	Senior house officer	0 (0)	1 (4.5)	0 (0)	1 (4.5)	1 (4.5)	3 (2.7)
Team includes cardiology/ critical care nurse- n(%)		17 (77.3)	16 (72.7)	16 (72.7)	15 (68.2)	20 (90.9)	84 (76.4)
Team includes member skilled in tracheal intubation- n(%)		20 (90.9)	15 (68.2)	19 (86.4)	19 (86.4)	18 (81.8)	91 (82.7)
†- Hospitals divided into quintiles based on risk adjusted survival rates (highest= highest risk-adjusted survival)							

		N	ROSC > 20 minutes n(%)	Hospital survival n(%)	N	Good neurological outcome n(%)
Total		12285	5412 (44.1)	1815 (14.8)	12168	1613 (13.3)
Sex						
	Male	7081	3036 (42.9)	1010 (14.3)	7018	903 (12.9)
	Female	5204	2376 (45.7)	805 (15.5)	5150	710 (13.8)
Hospital length of stay pre-arrest						
	0 days	1570	800 (51.0)	339 (21.6)	1541	299 (19.4)
	1 day	2276	1041 (45.7)	371 (16.3)	2247	329 (14.6)
	2-7 days	4873	2093 (43.0)	667 (13.7)	4834	598 (12.4)
	8 or more days	3566	1478 (41.4)	438 (12.3)	3546	387 (10.9)
Reason for attendance						
	Medical patient	10404	4531 (43.6)	1440 (13.8)	10314	1282 (12.4)
	Elective surgery patient	602	349 (58.0)	179 (29.7)	594	166 (27.9)
	Emergency surgery patient	810	346 (42.7)	114 (14.1)	800	99 (12.4)
	Trauma patient	453	172 (38.0)	69 (15.2)	446	55 (12.3)
	Staff/ visitor	9	8 (88.9)	8 (88.9)	9	8 (88.9)
	Outpatient	7	6 (85.7)	5 (71.4)	5	3 (60.0)
Location of arrest						
	Ward	10718	4679 (43.7)	1559 (14.5)	10627	1390 (13.1)
	Emergency admissions unit	1567	733 (46.8)	256 (16.3)	1541	223 (14.5)
Presenting rhythm						
	VF	916	615 (67.1)	309 (33.7)	899	280 (31.1)
	VT	297	219 (73.7)	143 (48.1)	288	131 (45.5)
	Shockable- unknown	62	43 (69.4)	22 (35.5)	61	20 (32.8)
	PEA	6683	2914 (43.6)	678 (10.1)	6628	580 (8.8)
	Asystole	3069	701 (22.8)	127 (4.1)	3063	114 (3.7)
	Bradycardia	10	9 (90.0)	4 (40.0)	9	3 (33.3)
	Non-shockable- unknown	230	137 (59.6)	60 (26.1)	228	55 (24.1)
	Unknown	1018	774 (76.0)	472 (46.4)	992	430 (43.3)
Patient deteriorating (not yet arrested) at team arrival						
	Yes	708	331 (46.8)	98 (13.8)	692	74 (10.7)
	No	11577	5081 (43.9)	1717 (14.8)	11476	1539 (13.4)
VF- Ventricular fibrillation; VT- ventricular tachycardia; PEA- pulseless electrical activity						







Electronic supplement

Model details

Calculation of risk adjusted survival rates

Using the *glmer* function from the *lme4* R package (version 1.1-19), which fits generalised linear mixed-effects models, hospital survival has been regressed against the pre-defined individual level confounders (see below) with trust level random effects. A risk adjusted hospital survival rate was then calculated for each trust by applying the inverse of the logit function to the intercept plus the trust's random effect (all confounders set to their reference level). This was then used to divide the trusts into quintiles.

Working with hospitals rather than trusts, a similar procedure was used to divide hospitals into quintiles.

Individual level confounders

The following individual level confounders have been incorporated into the analysis models:

- age (modelled using a restricted cubic spline with 4 degrees of freedom)
- sex (male/female)
- length of stay in hospital prior to 2222 call: categories as follows
 - 0 days
 - 1 day
 - 2-7 days
 - 8 or more days
- reason for admission to/attendance at/visit to hospital: categories as follows
 - D: patient - medical
 - L: patient - elective surgery
 - M: patient - emergency surgery
 - SV: staff or visitor
 - T: patient - trauma
 - U: outpatient
- location of arrest (categorical)
 - W: ward
 - Y: emergency admissions unit
- presenting/first documented rhythm: categories as follows
 - A: non-shockable - asystole
 - B: non-shockable - bradycardia
 - F: shockable - VF
 - N: non-shockable - unknown
 - P: non-shockable - PEA
 - S: shockable - unknown
 - T: shockable - VT
 - UV: unknown
- patient deteriorating (not yet arrested) at team arrival (yes/no)

These have been obtained from the NCAA database.

Trust level confounders

The following trust level confounders have been incorporated into the analysis models:

- number of beds;
- number of annual admissions.

The number of trust beds is taken from the resuscitation service survey. For the English trusts, the number of annual admissions is taken from the Hospital Episode Statistics (HES) for the financial year ending March 2017. Annual admissions for the Welsh trust is from the 2016/17 provider based statistics for NHS Wales. For the Northern Ireland trusts, total admissions for 2016/17 were allocated to individual trusts using ratios from 2013.

Bayesian models

The Bayesian models were run using the statistical software R (Version 3.5.1) and JAGS (Version 4.3.0). All the models were run using 2 chains, initialised with diffuse starting values, to produce a posterior sample of 100,000 after burn-in. Convergence was assumed if an examination of the trace plots for individual parameters was satisfactory and their Gelman-Rubin convergence statistics were below 1.05.

For the hierarchical models, despite setting the thinning parameter to 2, the effective sample size of the variables of interest was an order of magnitude lower than the posterior sample size (for the odds ratios for the resuscitation service factors the effective sample size was at least 3,500). Slow running precluded longer chains. By contrast, running speed and low effective sample size was not an issue for the non-hierarchical linear model used for the secondary analysis of the primary endpoint.

We also checked for sensitivity to alternative prior specifications. The results were robust. Posterior prediction was used to check the adequacy of the fit of the model to the data and this was satisfactory.

Characteristics of responding and non-responding hospitals

TABLE S1: Responding v non-responding hospitals

Variables	responders	non-responders
Hospital characteristics	N = 110	N = 70
Number of admissions ¹ :		
Mean(SD)	77390 (36518)	73701 (37231)
Median(lq,uq)	71563 (53901,91816)	68637 (46044,93360)
Patient characteristics	N = 12285	N = 7732
Age (years):		
Mean(SD)	74.7 (13.6)	74.5 (13.5)
Median(lq,uq)	78 (68,84)	77 (67,84)
Male, n(%)	7081 (57.6)	4481 (58.0)
LOS in hospital ² (days):		
Mean(SD)	7.7 (14.5)	7.3 (18.8)
Median(lq,uq)	3 (1,9)	3 (1,8)
Outcomes		
Hospital survival, n(%)	1815 (14.8)	1019 (13.2)
ROSC ³ > 20 minutes, n(%)	5412 (44.1)	3384 (43.8)
Favourable neurological outcome ⁴ , n(%)	1613 (13.3)	830 (10.9)

n: number of patients; %: percentage of patients;

SD: standard deviation; lq: lower quartile; uq: upper quartile.

¹ mean annual admissions based on all reported data over 2 year period between 1 January 2016 and 31 December 2017

² length of stay in hospital prior to 2222 call

³ return of spontaneous circulation

⁴ 264 patients with missing favourable neurological outcome are excluded

Analysis of secondary outcomes

TABLE S2: Odds ratio of secondary outcomes (ROSC > 20 minutes and favourable neurological outcome) for resuscitation service factors

Resuscitation Service Factor	ROSC > 20 minutes		favourable neurological outcome	
	median (95%CrI) ¹	probability odds ratio>1 ²	median (95%CrI) ¹	probability odds ratio>1 ²
Additional resuscitation officer for every 750 clinical staff	1.14 (0.87,1.44)	0.86	1.23 (0.86,1.66)	0.89
Hospital audits time to first shock	1.01 (0.85,1.19)	0.57	1.11 (0.87,1.36)	0.82
Hospital reviews cases of NCAA unexpected non-survivors	1.03 (0.83,1.23)	0.60	1.05 (0.80,1.34)	0.66
Arrest team meet at handover	0.88 (0.73,1.05)	0.08	0.86 (0.66,1.09)	0.11
Hot debrief	0.99 (0.80,1.21)	0.48	1.11 (0.83,1.44)	0.77
Cold debrief	1.15 (0.90,1.43)	0.89	0.69 (0.49,0.93)	0.01
Real-time AV feedback	1.06 (0.85,1.28)	0.71	0.83 (0.62,1.07)	0.09
Regular mock arrest provision	1.02 (0.80,1.26)	0.56	1.08 (0.77,1.42)	0.69
Infrequent mock arrest provision	0.95 (0.79,1.13)	0.29	1.12 (0.88,1.40)	0.82

¹posterior median (95% credible interval)

²probability resuscitation service factor increases odds of secondary outcome

Secondary analysis of primary outcome

TABLE S3: Change in risk adjusted hospital survival rate for resuscitation service factors

Resuscitation Service Factor	mean (95%CrI) ¹	probability of increase ²
Additional resuscitation officer for every 750 clinical staff	0.019 (-0.020,0.058)	0.83
Hospital audits time to first shock	0.013 (-0.015,0.039)	0.82
Hospital reviews cases of NCAA unexpected non-survivors	0.006 (-0.024,0.037)	0.65
Arrest team meet at handover	-0.021 (-0.050,0.008)	0.08
Hot debrief	0.005 (-0.029,0.039)	0.62
Cold debrief	-0.016 (-0.052,0.020)	0.19
Real-time AV feedback	-0.018 (-0.052,0.015)	0.15
Regular mock arrest provision	0.011 (-0.024,0.047)	0.74
Infrequent mock arrest provision	0.019 (-0.010,0.047)	0.91

¹posterior mean (95% credible interval)

²probability resuscitation service factor increases risk adjusted hospital survival rate