Predictors of Survival from Perioperative Cardiopulmonary Arrests

A Retrospective Analysis of 2,524 Events from the Get With The Guidelines-Resuscitation Registry

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ABSTRACT

Background: Perioperative cardiopulmonary arrests are uncommon and little is known about rates and predictors of in-hospital survival.

Methods: Using the Get With The Guidelines®-Resuscitation national in-hospital resuscitation registry, we identified all patients aged 18 yr or older who experienced an index, pulseless cardiac arrest in the operating room or within 24 h postoperatively. The primary outcome was survival to hospital discharge, and the secondary outcome was neurologically intact recovery among survivors. Multivariable logistic regression models using generalized estimating equation models were used to identify independent predictors of survival and neurologically intact survival.

Results: A total of 2,524 perioperative cardiopulmonary arrests were identified from 234 hospitals. The overall rate of survival to discharge was 31.7% (799/2,524), including 41.8% (254/608) for ventricular tachycardia and ventricular fibrillation, 30.5% (296/972) for asystole, and 26.4% (249/944) for pulseless electrical activity. Ventricular fibrillation and pulseless ventricular tachycardia were independently associated with improved survival. Asystolic arrests occurring in the operating room and postanesthesia care unit were associated with improved survival when compared to other perioperative locations. Among patients with neurological status assessment at discharge, the rate of neurologically intact survival was 64.0% (473/739). Prearrest neurological status at admission, patient age, inadequate natural airway, prearrest ventilatory support, duration of event, and event location were significant predictors of neurological status at discharge.

Conclusion: Among patients with a perioperative cardiac arrest, one in three survived to hospital discharge, and good neurological outcome was noted in two of three survivors.

What We Already Know about This Topic

- Perioperative cardiopulmonary arrests are uncommon events, and their morbidity and mortality have not been well-studied
- Using the Get With The Guidelines-Resuscitation national cardiopulmonary resuscitation registry, this study determined the presentation, management, and outcomes of arrests occurring in the operating room and the postoperative period within 24 h of surgery

What This Article Tells Us That Is New

- Among patients with a perioperative cardiac arrest, one in three survived to hospital discharge, and good neurological outcome was noted in two of three survivors

PERIOPERATIVE cardiopulmonary arrests are uncommon events, and their morbidity and mortality have not been well-studied. The early postoperative period poses additional risks to patients due to the proximate nature of anesthesia and surgical insults. Thus, several features of perioperative cardiac arrests are unique.[1] As with other specialized areas, such as the emergency room,[2] perioperative

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events may differ from cardiac arrests elsewhere in the hospital in terms of resuscitation response times and underlying etiology. Thus, survival outcomes may be different in these locations than those seen in general in-patient units.

In prior studies, survival rates from perioperative arrests[3–5] were higher than those reported in large multicenter in-hospital arrest studies.[6] Other studies have reported on the incidence and risk factors for perioperative cardiac arrests,[3–5] but these have typically been single-institution studies with small sample sizes (the largest study population of 223 patients),[4] raising the question of generalizability. There remain significant limitations in our knowledge of perioperative arrests. For instance, no prior study has described outcomes for cardiac arrests occurring in the early postoperative period or variability of survival in different postoperative locations. Such information may be important for anesthesiologists who are often involved in the decision making for the postoperative disposition of patients (floor status *vs.* telemetry *vs.* intensive care). In addition, the relationship between process-of-care measures (*e.g.*, time to epinephrine, intubation, and defibrillation) and outcomes in the perioperative setting is scant.

To better address these gaps in knowledge related to perioperative cardiac arrests, we set out to study the presentation, management, and outcomes of arrests occurring in the operating room (OR) and the postoperative period within 24 h of surgery.

Materials and Methods

Study Design

To achieve the study goals, we analyzed data from the multicenter Get With The Guidelines—Resuscitation (GWTG-R, formerly known as the National Registry for Cardiopulmonary Resuscitation)[7] database, an American Heart Association sponsored prospective, multisite, observational registry, because of its detailed collection of measures of care and outcomes for in-hospital cardiac arrests. The members of the American Heart Association GWTG-R Investigators are listed in appendix 1. The study design of the GWTG-R has been described previously in detail.[6] Briefly, a resuscitation event is defined as a pulseless cardiopulmonary arrest that requires chest compressions and/or defibrillation. Data abstraction for each cardiac arrest is performed by trained personnel at each participating institution.[7] Data accuracy within the GWTG-R is ensured through periodic chart review, and the mean error rate has been previously reported to be less than 2.4% for all data.[8] To allow for comparative analyses across multiple sites, data elements within the registry are standardized using Utstein-style definitions to ensure uniformity of data collection.[9] Oversight of data collection and analysis, integrity of the data, and research is provided by the American Heart Association.

The registry is currently the largest repository of information on in-hospital cardiopulmonary arrest from over 400 participating hospitals.[10] Because the GWTG-R data are deidentified and already exist, need for consent was waived by the Adult Research Task Force of the National Registry of Cardiopulmonary Resuscitation and the Executive Database Steering Committee of the American Heart Association.

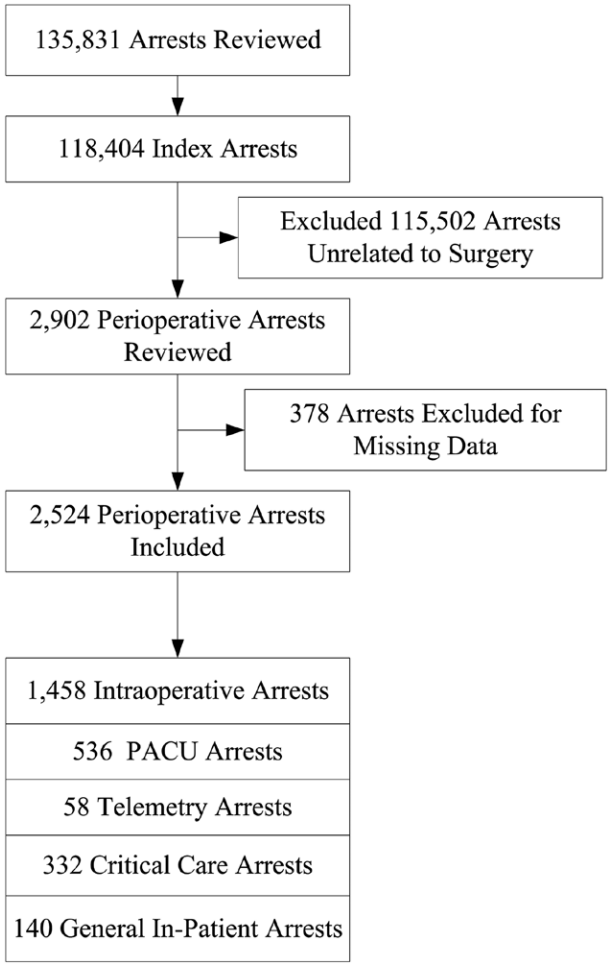

Fig. 1. Exclusion criteria and final study cohort. PACU = postanesthesia care unit.

Patient Population

Of 118,404 patients aged 18 yr or older who experienced an index, pulseless cardiac arrest from February 24, 2000, to August 3, 2008, we excluded 115,502 patients because their cardiac arrest did not occur in the OR, postanesthesia care unit (PACU), or any locations, within 24 h after leaving the PACU (fig. 1). An additional 378 patients were excluded due to missing data on first pulseless rhythm or survival outcomes. Our final study cohort comprised 2,524 patients with perioperative cardiac arrests.

Study Outcomes

The primary outcome measure was survival to hospital discharge. We examined as a secondary outcome measure neurologically intact survival among patients surviving to hospital discharge. Neurological outcome was assessed using previously described cerebral performance category (CPC) scores,[6] which describes patients as having no major disability (CPC = 1), moderate disability (CPC = 2), severe disability (CPC = 3),

Table 1. Baseline Characteristics of Perioperative Cardiopulmonary Arrests by Survival to Discharge Status

Characteristic	Survivors (n=799)	Nonsurvivors (n=1725)	*P* Value	Unadjusted Odds Ratio (95% CI)	Missing Data, n (%)
Age	63.2 ± 15.7	65.1 ± 18.1	<0.001	—	0 (0)
Male sex	446 (55.8)	980 (56.8)	0.640	1.0 (0.9–1.1)	6 (0.2)
White race	615 (82.1)	1,253 (77.7)	0.014	0.3 (1.1–1.6)	168 (6.6)
First documented rhythm					
Asystole	296 (37.0)	676 (39.2)	0.304	0.9 (0.8–1.1)	371 (12.8)
PEA	249 (31.2)	695 (40.3)	<0.001	0.7 (0.6–0.8)	371 (12.8)
PVT/VF	254 (31.8)	354 (20.5)	<0.001	1.6 (1.3–2.0)	371 (12.8)
Duration of event	14.3 ± 14.2	25.5 ± 19.6	<0.001	—	0 (0)
Length of hospital stay	15.4 ± 15.1	11.7 ± 6.3	<0.001	—	9 (0.3)
Admitting diagnosis					
Medical, cardiac	64 (8.1)	98 (5.7)	<0.001	1.5 (1.0–2.0)	28 (0.9)
Medical, noncardiac	60 (7.6)	224 (13.1)	<0.001	0.5 (0.4–0.7)	28 (0.9)
Surgical, cardiac	129 (16.4)	229 (13.4)	0.055	1.3 (1.0–1.6)	28 (0.9)
Surgical, noncardiac	516 (65.6)	994 (58.0)	0.001	0.3 (1.1–1.6)	28 (0.9)
Time of cardiac arrest					
After hours	67 (8.4)	324 (18.8)	<0.001	0.4 (0.3–0.5)	0 (0)
Weekend	88 (11.0)	381 (22.1)	<0.001	0.4 (0.3–0.6)	0 (0)
Event location					
Operating room	455 (56.9)	1,003 (58.1)	0.571	1.0 (0.8–1.1)	0 (0)
Postanesthesia care unit	214 (26.8)	32 (18.8)	<0.001	1.5 (1.2–1.9)	0 (0)
Intensive care area	76 (9.5)	256 (14.8)	<0.001	0.6 (0.5–0.8)	0 (0)
Telemetry/step-down	20 (2.5)	38 (2.1)	0.573	0.2 (0.7–2.1)	0 (0)
General in-patient area	34 (4.3)	106 (6.1)	0.054	0.7 (0.5–1.0)	0 (0)
Coexisting medical conditions					
Congestive heart failure at admission	55 (6.9)	175 (10.1)	0.008	0.7 (0.5–0.9)	0 (0)
Previous congestive heart failure	117 (14.6)	284 (16.4)	0.245	0.9 (0.7–1.1)	0 (0)
Myocardial infarction at admission	81 (10.1)	165 (9.6)	0.652	1.0 (0.8–1.4)	0 (0)
Previous myocardial infarction	130 (16.3)	280 (16.2)	0.981	1.0 (0.8–1.3)	0 (0)
Respiratory insufficiency	228 (28.5)	655 (38.0)	<0.001	0.7 (0.5–0.8)	0 (0)
Renal insufficiency	151 (18.9)	483 (28.0)	<0.001	0.6 (0.5–0.7)	0 (0)
Hepatic insufficiency	20 (2.5)	81 (4.7)	0.009	0.5 (0.3–0.9)	0 (0)
Metabolic or electrolyte derangement	60 (7.5)	263 (15.2)	<0.001	0.5 (0.3–0.6)	0 (0)
Baseline neurologic deficits	45 (5.6)	184 (10.7)	<0.001	0.5 (0.4–0.7)	0 (0)
Acute stroke	19 (2.4)	44 (2.6)	0.796	0.9 (0.5–1.6)	0 (0)
Acute nonstroke neurological disorder	32 (4.0)	106 (6.1)	0.028	0.6 (0.4–1.0)	0 (0)
Pneumonia	26 (3.3)	82 (4.8)	0.083	0.7 (0.4–1.1)	0 (0)
Sepsis	35 (4.4)	194 (11.2)	<0.001	0.4 (0.3–0.5)	0 (0)
Shock	188 (23.5)	708 (41.0)	<0.001	0.4 (0.4–0.5)	0 (0)
Major trauma	42 (5.3)	233 (13.5)	<0.001	0.4 (0.3–0.5)	0 (0)
Cancer	75 (9.4)	214 (12.4)	0.027	0.7 (0.6–1.0)	0 (0)
Immediate cause of arrest					
Active myocardial infarction	40 (5.0)	129 (7.5)	0.021	0.7 (0.5–1.0)	14 (0.5)
Arrhythmia	528 (66.4)	959 (55.9)	<0.001	1.6 (1.3–1.9)	14 (0.5)
Hypotension/hypoperfusion	290 (36.5)	1,025 (59.7)	<0.001	0.4 (0.3–0.5)	14 (0.5)
Acute pulmonary edema	6 (0.8)	30 (1.7)	0.051	0.4 (0.2–1.0)	14 (0.5)
Acute pneumothorax	6 (1.0)	14 (1.1)	0.800	0.9 (0.3–2.3)	744 (25.6)
Acute pulmonary embolism	14 (1.8)	47 (2.7)	0.139	0.6 (0.4–1.2)	14 (0.5)
Acute respiratory insufficiency	227 (28.6)	513 (29.9)	0.493	0.9 (0.8–1.1)	14 (0.5)
Inadequate invasive airway	13 (1.6)	38 (2.2)	0.339	0.7 (0.4–1.4)	14 (0.5)
Inadequate natural airway	36 (4.5)	37 (2.2)	0.001	2.2 (1.4–3.4)	14 (0.5)
Invasive airway displacement	6 (0.8)	10 (0.6)	0.614	0.3 (0.5–3.6)	14 (0.5)
Metabolic abnormality	32 (4.0)	218 (12.7)	<0.001	0.3 (0.2–0.4)	14 (0.5)
Invasive ventilation during or prior arrest	713 (89.2)	1,688 (97.9)	<0.001	0.2 (0.1–0.3)	0 (0)

(*continued*)

Table 1. Continued

Characteristic	Survivors (n = 799)	Nonsurvivors (n = 1,725)	*P* Value	Unadjusted Odds Ratio (95% CI)	Missing Data, n (%)
Neurological status at admission					
No major disability	566 (78.2)	865 (57.1)	<0.001	2.7 (2.2–3.3)	92 (3.1)
Moderate disability	115 (15.9)	394 (26.0)	<0.001	0.5 (0.4–0.7)	92 (3.1)
Severe disability	36 (5.0)	148 (9.8)	<0.001	0.5 (0.3–0.7)	92 (3.1)
Coma or vegetative state	7 (1.0)	109 (7.2)	<0.001	0.1 (0.1–0.3)	92 (3.1)

PEA = pulseless electrical activity; PVT/VF = pulseless ventricular tachycardia or ventricular fibrillation.

and coma or vegetative state (CPC = 4). For this study, we dichotomized patients as having neurologically intact survival (CPC = 1) or survival with neurological disability (CPC > 1). Of the patients who survived to hospital discharge (survivors), only those with both admission and discharge CPC recorded (n = 663 [82.9% of survivors]) were included in multivariate analyses of predictors of neurologically intact survival.

Statistical Analysis

Baseline patient characteristics were compared between survivors and nonsurvivors with Pearson chi-square test for discrete variables, *t* test for normally distributed continuous data, and Wilcoxon rank sum test for nonnormally distributed variables.

We then constructed separate multivariable models to identify predictors of survival to discharge and neurologically intact survival. Variables with a univariate association with survival ($P < 0.10$) were considered for model inclusion. Candidate patient-level variables included admitting diagnosis (medical, cardiac; medical, noncardiac; surgical, cardiac; or surgical, noncardiac) and presence or absence of coexisting medical conditions at the time of cardiac arrest (respiratory, renal, or hepatic insufficiency; congestive heart failure, metabolic or electrolyte derangements; pneumonia; neurological disorders; shock; sepsis; major trauma, or cancer). Additionally, we controlled for variables related to the cardiac arrest, including initial cardiac rhythm (asystole, pulseless electrical activity [PEA], pulseless ventricular tachycardia [PVT], or ventricular fibrillation [VF]), duration of cardiac arrest, time of cardiac arrest (during work hours or during after-hours periods [*i.e.*, 5.00 pm to 8.00 am], and weekend events. Consistent with previous literature,[8,10] shockable rhythms PVT and VF were analyzed together as one rhythm type. For models assessing neurologically intact survival among survivors, we also included as a binary covariate prearrest neurological status (baseline CPC score 1 *vs.* other CPC score). As the data in the GWTG-R database are derived from multiple sites of differing volume, all models used generalized estimating equation methodology with an exchangeable correlation matrix to control for patient clustering at the facility level. Collinearity was evaluated on all pairs of variables to assess for independence. The magnitudes of the standard errors were used as additional measures of collinearity. The model test of significance was used to investigate model performance. The resultant chi-square statistic value is a measure of the relationship between observed and expected frequencies. A $P < 0.05$ in this test denotes that the null hypothesis is rejected. If the test was significant, linear relationships between predictors and log odds of outcome for continuous variables were further investigated. Model overfitting was limited by ensuring that more than 10 subjects per independent variable were included in the model.

Secondary analyses were performed to explore the differences in outcomes relating to initial rhythm type and presenting location (intraoperative, PACU, telemetry/step-down, intensive care unit [ICU], or general in-patient area). For this, we assessed the unadjusted relationship between process-of-care measures (time to administration of epinephrine, invasive airway placement, and defibrillation), event location, and survival. Groups were compared using *t* test for normally distributed continuous data and Wilcoxon rank sum test for nonnormally distributed variables. Additionally, multivariate models were developed for evaluating risk factors for survival to discharge for each primary rhythm type. Finally, we examined the relationship between the comorbid disease burden (defined as the total number of preoperative comorbidities documented at the time of the arrest) and outcomes (survival and good neurological status, defined as a CPC 1). For this analysis, we compared increasing number of coexisting medical conditions with the binary outcomes of interest using Pearson chi-square test and Fischer exact test as appropriate. Statistical analyses were performed using Stata 10 (StataCorp LP, College Station, TX).

Missing data analyses were performed to compare between cases included and excluded from the general estimating equation models. Survival to hospital discharge (27.7% *vs.* 32.4%; $P = 0.056$), admission CPC (66.9% *vs.* 63.1%; $P = 0.451$), and discharge CPC (67.7% *vs.* 63.6%; $P = 0.517$) were similar in the missing data and included patients' groups. In order to explore and present the missing data's potential influence on the estimates of risk, data imputation was performed using the following methodology. The number of missing values was assessed for key variables used in the analysis. Only missing data for the predictors were imputed. We employed multiple imputation with IVEware Version 0.1 (University of Michigan, Ann Arbor, Michigan) for missing data. IVEware is an imputation and

Table 2. Independent Predictors of Survival to Discharge and Good Neurological Outcome in Perioperative Arrests

	Survival to Discharge			
	Preimputation		Postimputation for Missing Data	
Risk Factor	Odds Ratio (95% CI)	*P* Value	Odds Ratio (95% CI)	*P* Value
Acute nonstroke neurological event	1.02 (0.68–1.53)	0.918	1.08 (0.72–1.62)	0.712
Baseline depression in neurological status	0.64 (0.41–1.01)	0.055	0.71 (0.47–1.06)	0.095
Congestive heart failure during admission	0.58 (0.41–0.83)	0.003	0.59 (0.41–0.85)	0.005
Hepatic insufficiency	0.62 (0.36–1.08)	0.092	0.66 (0.38–1.15)	0.142
Hypotension/hypoperfusion	0.54 (0.43–0.67)	<0.001	0.51 (0.41–0.63)	<0.001
Metastatic or hematologic malignancy	0.53 (0.38–0.74)	<0.001	0.63 (0.47–0.83)	0.001
Metabolic and electrolyte abnormality	0.67 (0.44–1.02)	0.064	0.64 (0.43–0.96)	0.029
Renal insufficiency	0.69 (0.53–0.88)	0.003	0.66 (0.52–0.85)	0.001
Respiratory failure	0.82 (0.65–1.03)	0.089	0.91 (0.73–1.13)	0.401
Septicemia	0.46 (0.28–0.74)	0.002	0.45 (0.28–0.72)	0.001
Active or evolving myocardial infarction	0.67 (0.42–1.07)	0.097	0.58 (0.36–0.93)	0.025
Inadequate natural airway	2.39 (1.20–4.76)	0.013	1.79 (1.00–3.22)	0.051
Arrhythmia	1.42 (1.17–1.73)	<0.001	1.37 (1.13–1.66)	0.001
After hours	0.56 (0.42–0.88)	0.001	0.61 (0.52–0.8)	<0.001
Arrest rhythm (PEA reference)				
Asystole	1.00 (0.77–1.31)	0.993	0.97 (0.78–1.21)	0.78
PVT/VF (shockable rhythms)	1.60 (1.16–2.20)	0.004	1.54 (1.20–1.98)	0.001
White *vs.* nonwhite	1.22 (0.94–1.57)	0.135	1.05 (0.84–1.33)	0.663
Event location (general in-patient unit—reference)				
Operating room	1.38 (0.83–2.30)	0.215	1.07 (0.69–1.66)	0.758
PACU	2.03 (1.16–3.56)	0.013	1.57 (0.97–2.52)	0.064
Telemetry	1.22 (0.50–2.99)	0.658	1.02 (0.46–2.27)	0.958
Intensive care area	0.96 (0.52–1.77)	0.894	0.70 (0.40–1.21)	0.2
Weekend	0.62 (0.45–0.86)	0.004	0.53 (0.39–0.71)	<0.001
Invasive ventilation in place prearrest	0.28 (0.17–0.45)	<0.001	0.44 (0.33–0.59)	<0.001
Illness Category (medical noncardiac—reference value)				
Medical cardiac	2.04 (1.13–3.72)	0.019	1.91 (1.15–3.19)	0.013
Surgical cardiac	1.65 (1.03–2.65)	0.039	1.86 (1.22–2.84)	0.004
Surgical noncardiac	1.44 (1.00–2.08)	0.048	1.50 (1.09–2.06)	0.013
Trauma	0.20 (0.09–0.46)	<0.001	0.25 (0.12–0.51)	<0.001
Age at hospital admission	0.98 (0.97–0.99)	<0.001	0.98 (0.97–0.99)	<0.001
Duration of event	0.96 (0.95–0.96)	<0.001	0.95 (0.95–0.96)	<0.001
Admission CPC score 1	Not included	—	Not included	—

CPC = cerebral performance category; PACU = postanesthesia care unit; PEA = pulseless electrical activity; PVT/VF = pulseless ventricular tachycardia or ventricular fibrillation.

variance estimation software that creates single or multiple imputations of missing values using the Sequential Regression Imputation Method.[11,12] IVEware also creates partial or full synthetic data sets using the sequential regression approach to protect confidentiality and limit statistical disclosure and can combine information from multiple sources by vertically concatenating data sets and multiply imputing the missing portions to create larger rectangular data sets. For our imputation, IVEware was used to impute data through SAS version 9.2 (SAS Inc., Cary, NC). This approach allowed us to handle complex data structures that were created from a large number of variables with mixed formats (dichotomous, categorical, continuous, counts, and others). For this analysis, five imputations were performed and the datasets were assembled into one dataset so analysis could be conducted. After imputation, Stata 10 was utilized to analyze multivariate models for major outcome measures using General Estimation Equation to account for clustering at the facility level. The same syntax was used to recreate the multivariate models after imputation to provide information on the influence of missing data on risk estimates.

Results

Of 2,524 patients from 234 hospitals, 1,458 (57.7%) had a cardiac arrest in the OR and the rest had arrests in the postoperative setting (fig. 1). Return of spontaneous circulation occurred in 1,485 patients (58.7%), 1,151 patients (45.5%)

Table 2. Continued

	Good Neurological Outcome			
	Preimputation		Postimputation for Missing Data	
Risk Factor	Odds Ratio (95% CI)	*P* Value	Odds Ratio (95% CI)	*P* Value
Acute nonstroke neurological event	0.90 (0.29–2.78)	0.855	0.94 (0.35–2.52)	0.909
Baseline depression in neurological status	0.46 (0.21–1.00)	0.05	0.61 (0.27–1.41)	0.249
Congestive heart failure during admission	1.07 (0.37–3.04)	0.905	1.03 (0.44–2.42)	0.941
Hepatic insufficiency	0.83 (0.15–4.56)	0.832	0.77 (0.25–2.36)	0.653
Hypotension/hypoperfusion	0.71 (0.43–1.19)	0.198	0.84 (0.56–1.26)	0.387
Metastatic or hematologic malignancy	0.73 (0.36–1.47)	0.378	0.86 (0.52–1.43)	0.568
Metabolic and electrolyte abnormality	1.90 (0.79–4.55)	0.152	1.38 (0.79–2.43)	0.257
Renal insufficiency	0.63 (0.32–1.22)	0.171	0.64 (0.38–1.08)	0.093
Respiratory failure	0.90 (0.51–1.59)	0.712	0.94 (0.58–1.54)	0.812
Septicemia	0.24 (0.07–0.84)	0.026	0.47 (0.16–1.40)	0.177
Active or evolving myocardial infarction	1.19 (0.49–2.84)	0.704	1.05 (0.49–2.26)	0.899
Inadequate natural airway	0.48 (0.20–1.19)	0.113	0.44 (0.21–0.92)	0.029
Arrhythmia	0.85 (0.54–1.35)	0.5	0.78 (0.54–1.13)	0.195
After hours	1.32 (0.43–4.00)	0.626	0.68 (0.28–1.62)	0.38
Arrest rhythm (PEA reference)				
Asystole	0.79 (0.43–1.45)	0.449	0.94 (0.63–1.39)	0.75
PVT/VF (shockable rhythms)	0.91 (0.49–1.70)	0.76	1.04 (0.67–1.61)	0.866
White *vs.* nonwhite	1.73 (0.94–3.18)	0.081	1.52 (0.94–2.47)	0.088
Event location (general in-patient unit—reference)				
Operating room	5.77 (1.74–19.10)	0.004	1.64 (1.16–4.39)	0.041
PACU	5.64 (1.77–17.95)	0.003	1.72 (1.07–4.55)	0.049
Telemetry	2.21 (0.62–7.95)	0.223	0.93 (0.23–3.74)	0.919
Intensive care area	6.79 (1.77–26.05)	0.005	1.72 (0.51–5.85)	0.383
Weekend	1.65 (0.73–3.74)	0.229	1.15 (0.64–2.08)	0.637
Invasive ventilation in place prearrest	0.08 (0.03–0.21)	<0.001	0.59 (0.35–0.99)	0.046
Illness Category (medical noncardiac—reference value)				
Medical cardiac	1.66 (0.58–4.79)	0.349	2.27 (0.95–5.39)	0.064
Surgical cardiac	1.88 (0.70–5.03)	0.209	1.88 (0.87–4.08)	0.11
Surgical noncardiac	1.88 (0.83–4.25)	0.128	1.65 (0.87–3.11)	0.122
Trauma	4.56 (0.26–81.53)	0.302	3.69 (0.73–18.70)	0.115
Age at hospital admission	0.98 (0.96–0.99)	0.001	0.98 (0.97–0.99)	0.003
Duration of event	0.99 (0.97–1.00)	0.047	0.98 (0.97–0.99)	0.001
Admission CPC score 1	48.84 (23.53–101.38)	<0.001	21.69 (12.52–37.57)	<0.001

survived to 24 h after their cardiac arrest, and 799 (31.7%) survived to hospital discharge. Neurologically intact survival was observed in 473 (64.0%) of 739 survivors with valid CPC scores at discharge.

Results are clustered around key areas relevant to perioperative arrests listed below: primary arrest rhythm, location-specific differences, patient-level associations, event-level associations, and neurological status at admission and outcomes. Univariate analyses are presented in table 1. Multiple adjusted analyses presented in tables 2 and 3, and appendices 2–7 are provided to compare estimates of risk factors before and after data imputation for missing variables. All estimates presented in the following sections refer to the postimputation data analyses. Patients excluded due to any missing data were similar in baseline characteristics to patients in the final study cohort, except that the excluded patients had lower rates of previous myocardial infarction (4.1% *vs.* 6.8%, $P = 0.045$), septicemia (5.4% *vs.* 9.0%; $P = 0.019$), arrhythmia (50.8% *vs.* 59.3%; $P = 0.042$), and metabolic derangement (5.1% *vs.* 10.0%, $P = 0.001$). Patients excluded for missing data on primary rhythm did not differ significantly from those without missing data with regard to survival to discharge (35.4% *vs.* 33.3%; $P = 0.362$) and good neurological outcome (67.7% *vs.* 63.3%; $P = 0.306$).

Primary Arrest Rhythm

Asystole was the most commonly encountered rhythm, but survivors were more likely to have a shockable initial cardiac arrest rhythm (31.8% *vs.* 20.5%; $P < 0.001$) compared with

nonsurvivors (table 1). After adjusting for several patient-level and event-level variables, PVT/VF alone was significantly associated with survival to 24 h postarrest and survival to discharge (tables 2 and 3; appendices 2 and 3). Adjusted analyses of survival outcomes stratified by first documented pulseless rhythm are described in table 3 (and appendices 4–6). There were no rhythm-specific differences in neurological outcomes on adjusted models (table 2, appendix 7). In adjusted sub-analyses, arrest location, increasing age, and longer duration of arrest were common independent associations with worse survival to discharge across all the three primary rhythms (appendices 4–6).

Location-specific Differences

There were significant differences in survival and neurological outcome by hospital location of arrest. The majority of arrests occurred in the OR (1458/2524). Survival rates were highest in PACU arrests (214/536; 39.8%) followed by telemetry (20/58; 35.1%), OR arrests (455/185; 31.2%), general in-patient areas (34/140; 24.3%), and ICU locations (76/332; 23.0%). Arrests in the OR, PACU, and ICU were associated with significantly shorter time to epinephrine, whereas OR and PACU arrests were associated with significantly shorter times to invasive airway placement. There were no location-specific differences in the time to defibrillation (table 4).

On adjusted analyses, arrest location was not associated with survival to discharge. However, significant location-specific differences were observed in adjusted sub-analyses of survival to discharge within each arrest rhythm. Among patients exhibiting asystole as the first documented pulseless rhythm (appendix 5), intraoperative (adjusted odds ratio, 1.4; 95% CI, 1.0–2.6; $P = 0.047$) and PACU (adjusted odds ratio, 2.0; 95% CI, 1.0– 4.1; $P = 0.044$) locations were significantly better survival to discharge compared to general in-patient locations (fig. 2). ICU location was associated with worse survival following PEA arrests (adjusted odds ratio, 0.4; 95% CI, 0.2–0.8; $P = 0.012$). In contrast, telemetry (adjusted odds ratio, 5.7; 95% CI, 1.1–29.6; $P = 0.038$) and ICU arrests (adjusted odds ratio, 1.9; 95% CI, 1.1–5.1; $P = 0.041$) were significantly associated with improved survival following PVT/VF arrests in comparison with general in-patient arrests

Intraoperative (adjusted odds ratio, 1.6; 95% CI, 1.2–4.4; $P = 0.041$) and PACU (adjusted odds ratio, 1.1; 95% CI, 1.1–4.6; $P = 0.05$) were significantly associated with better neurological outcomes in comparison to the events occurring in the general in-patient location (table 2). On sensitivity analyses, after exclusion of patients with CPC scores >1, location was not associated with neurological outcome, suggesting that patient factors likely play a large role in neurological recovery from perioperative arrest.

Patient-level Associations

The following variables were each associated with lower survival rates to discharge on univariate analyses (table 1): Older age, congestive heart failure during admission (23.9% survival *vs.* 32.4% control survival; $P = 0.008$), respiratory insufficiency (25.8% survival *vs.* 34.8% control survival; $P < 0.001$), renal insufficiency (23.8% survival *vs.* 32.1% control survival; $P = 0.028$), hepatic insufficiency (19.8% survival *vs.* 32.2% control survival; $P = 0.009$), baseline depression in neurological status (19.7% survival *vs.* 32.9% control survival; $P < 0.001$), acute nonstroke neurological event (23.2% survival *vs.* 32.1% control survival; $P = 0.028$), septicemia (15.3% survival *vs.* 33.3% control survival; $P < 0.001$), shock (21.0% survival *vs.* 37.5% control survival; $P < 0.001$), major trauma (15.3% survival *vs.* 33.7% control survival; $P < 0.001$), metabolic abnormality (18.6% survival *vs.* 33.6% control survival; $P < 0.001$), and metastatic or hematologic malignancy (26.0% survival *vs.* 32.4% control survival; $P = 0.027$). While myocardial infarction at admission showed no relationship with survival, the survival rate was lower in those cases in which the arrest was specifically attributed to the myocardial infarction (23.7% survival *vs.* 32.2% control survival; $P = 0.021$).

Arrests attributed to arrhythmia (35.5% survival *vs.* 26.1% control survival; $P < 0.001$), inadequate natural airway (49.3% survival *vs.* 31.1% control survival; $P = 0.01$), and white race (32.9% survival *vs.* 27.1% control survival; $P < 0.001$) had higher rates of survival.

After multivariable adjustment, several patient-level characteristics and medical conditions were associated with lower survival from perioperative arrests (table 2), including age (adjusted odds ratio per additional year, 0.98; 95% CI, 0.96–0.99), congestive heart failure during current admission (adjusted odds ratio, 0.6; 95% CI, 0.4–0.9), shock (adjusted odds ratio, 0.5; 95% CI, 0.4–0.6), metabolic abnormality (adjusted odds ratio, 0.6; 95% CI, 0.4–0.9), metastatic or hematologic malignancy (adjusted odds ratio, 0.6; 95% CI, 0.4–0.9), renal insufficiency (adjusted odds ratio, 0.7; 95% CI, 0.5–0.9), sepsis (adjusted odds ratio, 0.5; 95% CI, 0.3–0.7), active or evolving myocardial infarction (adjusted odds ratio, 0.6; 95% CI, 0.4–0.9), and trauma (adjusted odds ratio, 0.3; 95% CI, 0.1–0.5). Arrhythmic cause of arrest (adjusted odds ratio, 1.4; 95% CI, 1.1–1.7) was associated with higher adjusted odds of survival to discharge. Age was the only patient-level risk factor associated with both reduced survival to discharge and poor neurological outcome. Inadequate natural airway and admission neurological status were the other patient-level factors associated with neurological recovery (table 2).

Event-level Associations

Of the process–of-care measures, time to epinephrine administration was not related to any of the outcome measures (table 4). Time to defibrillation was related to all survival end points except neurological outcomes in survivors. Time to invasive airway placement was related to 24-h survival and neurological outcomes, but not survival to discharge.

Table 3. Summary of Study End Points and Adjusted Survival Rates by Primary Arrest Rhythm Type

	PEA		Asystole			PVT/VF		
End Point	Frequency (%)	AOR (95% CI)	Frequency (%)	AOR (95% CI)	*P* Value	Frequency (%)	AOR (95% CI)	*P* Value
ROSC	533/944 (56.5%)	Reference	551/972 (56.7%)	1.0 (0.8–1.2)	0.901	401/608 (65.9%)	1.2 (1–1.6)	0.106
Survival to 24 h	395/944 (41.8%)	Reference	436/972 (44.9%)	1.0 (0.9–1.3)	0.772	320/608 (52.6%)	1.3 (1.0–1.7)	0.032
Survival to discharge	249/944 (26.3%)	Reference	296/972 (30.5%)	1.0 (0.8–1.2)	0.78	254/608 (41.8%)	1.5 (1.2–2.0)	0.001
Good neurological outcome	144/234 (61.5%)	Reference	178/272 (65.4%)	0.9 (0.6–1.4)	0.75	151/233 (64.8%)	1.0 (0.7–1.6)	0.866

Adjusted odds ratios are adjusted for acute nonstroke neurological event, baseline depression in neurological status, congestive heart failure during admission, hepatic insufficiency, hypotension, metastatic or hematologic malignancy, metabolic and electrolyte abnormality, renal insufficiency, respiratory failure, septicemia, active or evolving myocardial infarction, inadequate natural airway, invasive ventilation, arrhythmia, time of day, weekend, location of arrest, admission diagnosis, and age. Admission cerebral performance category score was included in adjusted model for neurological outcome. Model comparisons for neurological outcomes were made between survivors discharged with no major disability and those with a moderate degree of disability or worse. See appendices 2–4 for full model outputs. Multiple imputations and bootstrapping were performed to uncover hidden estimates for covariates included in the model. Estimates provided in this table are derived from postimputation adjusted analyses.

AOR = adjusted odds ratio; PEA = pulseless electrical activity; PVT/VF = pulseless ventricular tachycardia or ventricular fibrillation; ROSC = return of spontaneous circulation.

After multivariable adjustment, the event-level variables associated with survival to discharge included duration of event (adjusted odds ratio, 0.96; 95% CI, 0.95–0.96; $P < 0.001$), weekend arrests (adjusted odds ratio, 0.5; 95% CI, 0.4–0.7), after-hours arrests (adjusted odds ratio, 0.6; 95% CI, 0.5–0.8), and need for invasive ventilation (adjusted odds ratio, 0.4; 95% CI, 0.3–0.6). Duration of event (adjusted odds ratio, 0.98; 95% CI,

Table 4. Relationship of Event Location, Process-of-Care Measures, and Outcomes

	Time to Epinephrine	Time to Defibrillation	Time to Invasive Airway
Event location			
General inpatient	4 (0, 7)	4 (1, 7)	7 (5, 10)
OR	0 (0, 2)	1 (0, 3)	2 (0, 5)
PACU	1 (0, 3)	1 (0, 4)	3 (1, 6)
Telemetry	3 (1, 5)	2 (1, 3)	8 (3, 10)
ICU	0 (0, 3)	1 (0, 2)	8 (4, 10)
P value	<0.001*	0.06	<0.001*
Event survival			
Survived event	0 (0, 3)	0 (0, 3)	4 (1, 7)
Nonsurvivors	1 (0, 3)	1 (1, 5)	4 (1, 8)
P value	0.48	0.01*	0.25
24-h survival			
Survived 24 h	0 (0, 3)	0 (0, 3)	3 (1, 7)
Nonsurvivors	1 (0, 3)	1 (1, 5)	5 (1, 8)
P value	0.28	0.01*	0.03*
Survival to discharge			
Survived to discharge	0 (0, 3)	0 (0, 3)	3 (1, 7)
Nonsurvivors	1 (0, 3)	1 (1, 4)	4 (1, 8)
P value	0.56	0.01*	0.15
Neurological outcome			
Good neurological status	1 (0, 3)	1 (0, 2)	3 (1, 6)
Neurological injury	1 (0, 3)	1 (0, 5)	5 (2, 7)
P value	0.24	0.76	0.03*

Median (25th, 75th centiles) values are displayed. Good neurological outcome refers to Cerebral Performance Score of 1. Asymptotic significances are displayed.

* The significance level is 0.05.

ICU = intensive care unit; OR = operating room; PACU = postanesthesia care unit.

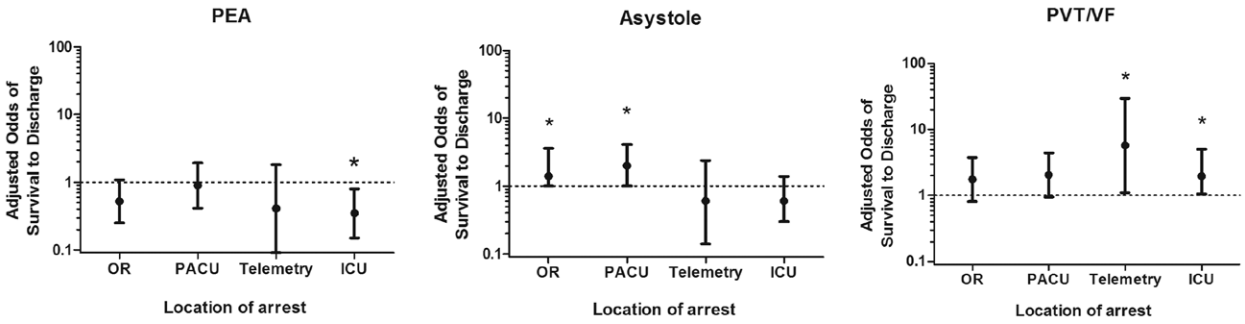

Fig. 2. Adjusted odds ratios of survival to hospital discharge (with 95% CIs) stratified by primary rhythm and hospital location. General inpatient locations were considered the reference value for each rhythm type and location. Asystolic events occurring in the operating room (OR) and postanesthesia care unit (PACU) were independently associated with survival to discharge compared to general inpatient arrests. Pulseless electrical activity (PEA) arrests were associated with worse survival to discharge in intensive care unit (ICU) locations. Telemetry and ICU locations were independently associated with survival to discharge in pulseless ventricular tachycardia (PVT)/ventricular fibrillation (VF) arrests. See appendices 5–7 for full model outputs. * $P < 0.05$ on adjusted analyses.

0.97–0.99) and need for invasive ventilation (adjusted odds ratio, 0.6; 95% CI, 0.4–0.9) were both associated with neurological outcomes on adjusted analyses.

Neurological Status at Admission and Outcomes

Admission CPC score of 1 was noted in 1,431 patients (among 2,240 patients with recorded admission CPC scores), of whom 566 survived to hospital discharge. Of these survivors with admission CPC1, 445 patients (80%) had CPC1 at discharge. Thus, 31.1% of patients who were admitted to hospital with CPC1 were discharged in a neurologically intact state following perioperative cardiac arrests. The strongest patient-level risk factor associated with neurologically intact survival was admission CPC score of 1 (table 2; adjusted odds ratio, 21.7; 95% CI, 12.5–37.6).

The relationship between the number of preoperative coexisting medical conditions and outcomes is described in figure 3. Survival to discharge decreased with increasing neurologic disability at admission, from 39.6% (566/1,431) for those with no major disability, 22.6% (115/509) for those with moderate disability, 19.6% (36/184) for those with severe disability, and 6% (7/116) for those in a coma or vegetative state ($P < 0.001$). In patients with good baseline neurological status, number of coexisting medical conditions was associated with worse survival to discharge ($P < 0.001$) and worse survival at 24 h ($P = 0.001$) but not survival of event ($P = 0.42$) or neurological outcome among those surviving to hospital discharge ($P = 0.64$). In patients with preevent neurologic deficits, number of coexisting medical conditions was not associated with any of the outcome measures (event survival, $P = 0.76$; 24-h survival, $P = 0.19$; survival to discharge, $P = 0.39$; good neurological outcome, $P = 0.77$).

Discussion

In a large cohort of patients with perioperative cardiac arrests, we found that one in three patients survived to hospital discharge, representing a significantly higher survival rate than previous studies on in-hospital arrests on general hospital floors.[6,13,14] Survival after arrests with shockable rhythms are significantly better than asystole and PEA arrests. Asystolic arrests in the OR and PACU were associated with better survival than asystolic arrests in other locations. Notably, location-specific differences in process-of-care measures were observed, suggesting variability in response times that may contribute to survival and neurological outcomes for perioperative patients with cardiac arrest.

The overall survival-to-discharge rates in this study are significantly higher than that in previous reports of in-hospital arrests from within the GWTG-R database (15.3–17%),[2,6,13,14] but confirms previous reported rates on survival from perioperative arrests.[4] One putative reason for this overall survival benefit seen in perioperative arrests is because surgical causes for cardiac arrest are more likely to be reversible. Alternatively, the immediate availability of physician led care in the OR and the PACU could improve survival from cardiac arrest by influencing the speed and quality of response.[2]

Primary Arrest Rhythms

There were significantly higher survival rates across all primary rhythm types (asystole, 30.5%; PEA, 26.4%; and PVT/VF, 41.8%) compared to that in previous in-hospital GWTG-R data (asystole, 10%; PEA, 10%; VF, 34%; and PVT, 35%).[6] In particular, the high survival rates from asystolic perioperative arrests are a unique finding of the current study, reflecting potentially reversible causes. In a previous subanalysis of 24 patients with anesthesia-attributed arrests, asystole was associated with a much higher survival rate (80% survival to discharge),[4] related to a predominance of medication and airway causes. In addition, location-specific differences in survival outcomes with asystole appear to support the view that immediate availability of anesthesia providers in the intraoperative and PACU locations may

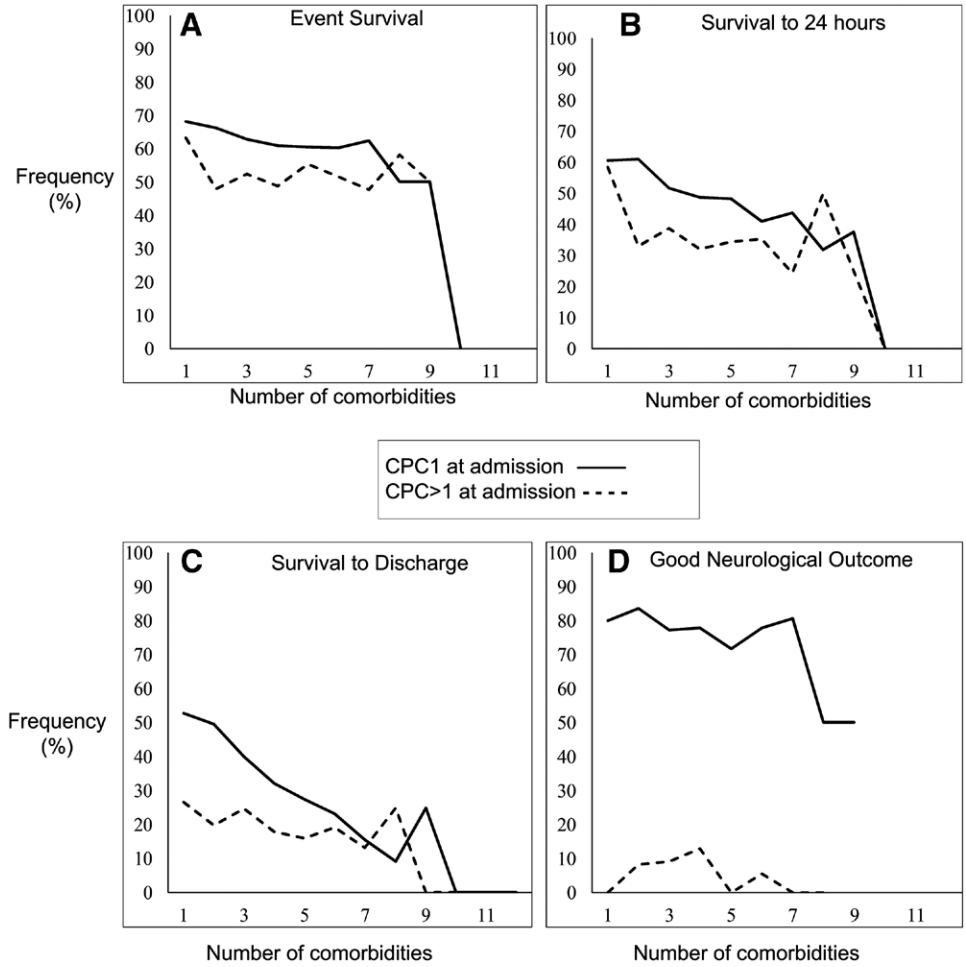

Fig. 3. Relationship of number of coexisting medical conditions and perioperative cardiac arrest outcomes. (*A*) Event survival, (*B*) survival to 24 h after event, (*C*) survival to discharge, (*D*) good neurological outcome (cerebral performance category [CPC] 1) at discharge. The X-axis shows number of coexisting medical conditions and Y-axis shows frequency (%) of outcome. *Solid lines* represent patients with good neurological status (CPC 1) at admission and interrupted lines represent patients with baseline neurologic deficits at admission (CPC 2–4). There is no relationship between number of comorbidities and neurologically intact survival in patients without baseline neurologic deficits at admission.

contribute significantly to improved outcomes in comparison with other locations. This association may be important especially in the context of the modifiable risk such as arrhythmic cause of asystolic arrest, which was observed to have improved survival. Thus, while asystole may indicate a dismal prognosis for out-of-hospital arrest, perioperative asystole in the perioperative setting should be treated aggressively. Intact survival appears to depend less on the presenting rhythm, and more on the etiology of arrest, timing of interventions, and quality of advanced cardiac life support.

Location-specific Differences

Significant location-specific differences have been described for time to invasive airway placement in overall in-hospital arrest literature.[14] The first 24 h after surgery are associated with a heightened risk of respiratory failure needing emergent airway intervention,[13,15] suggesting that delays in definitive airway management may be of greater importance in perioperative arrest outcomes. In the current study, time to invasive airway placement was related to 24-h survival and neurological outcomes, but not survival to discharge. The faster times to defibrillation, epinephrine administration, and invasive airway placement seen in the OR and PACU support the hypothesis that ready availability of skilled perioperative care directly impacts clinical response to cardiac arrest. It has been previously shown by others that defibrillation within 2 min of the arrest improves survival from PVT/VF arrests (39.3 *vs.* 22.2% for delayed defibrillation).[8] In our study, only ≈20% of the arrests were PVT/VF and survivors had shorter time to defibrillation. However, as trauma and shock were independently associated with worse survival to discharge with PVT/VF arrests, intraoperative PVT/VF arrests associated with these risk factors were less likely to be responsive to defibrillation. Thus, the OR may be the one location where speed of defibrillation offers little benefit for

the patient suffering from surgical exsanguination.[10] This may also explain the higher survival seen with PVT/VF arrests in postoperative locations (telemetry, ICU) as they are generally less likely to encounter major exsanguination and more likely to have other causes of PVT/VF arrest.

Decisions on location of postoperative care may be extremely important, and our study provides some insight into the location-specific differences in outcomes of high-risk patients. The finding that neurological outcomes are independently better in telemetry or ICU patients compared to general in-patient areas supports the value of increased intensity of monitoring in high-risk patients in the postoperative period. There is evolving evidence that patient surveillance systems[16] on general care units, but not just continuous pulse oximetry monitoring[17] may reduce morbidity. Our data suggest that the presence or immediate availability of skilled care (seen with PACU, ICU, and, to a lesser extent, telemetry beds) may be crucial in modifying survival from early postoperative cardiac arrests. Additional supportive evidence for this is the significantly shorter time to epinephrine administration and invasive airway placement seen in the OR and PACU in comparison to general care locations.

Patient-level and Event-level Associations

Previously, Peberdy *et al.*[7] found that survival outcomes were substantially lower during the night hours and the weekend, with the greatest effect-size noted for arrests in the OR and postoperative care unit. Chan *et al.*[8] also demonstrated that survival rates from in-hospital cardiac arrest were lower during nights and weekends, even when adjusted for potentially confounding patient-related, event-related, and hospital characteristics. In the current study, we identified lower odds of survival during night-time hours and weekends. It is possible that, in common with in-hospital arrests from other locations, other unmeasured system factors contribute to the observed time- and day-related differences in survival outcomes. This finding illustrates the limitations of therapy despite fairly intense one-on-one management with faculty anesthesiologist and surgeons.

Measures of acuity of response in the current study, namely, time to invasive airway placement and epinephrine administration, were associated with better survival rates. This finding suggests that anesthesiologists have the opportunity to modify several factors that can directly influence outcomes from arrests. On the contrary, the lower survival out of hours may reflect the lack of breadth of clinician resources and limited choices for delaying surgery due to greater severity of the primary surgical condition. These findings confirms Sprung's data[4] and mirror findings from the National Confidential Enquiry into Patient Outcome and Deaths.[18] However, this finding needs to be viewed in the context of emerging evidence that elective general surgery is safe during late hours with careful provision for appropriate perioperative care.[19] Thus, it may be possible to modify survival outcomes in high-risk emergent surgical patients by preferentially scheduling such cases during more routine hours, ensuring more appropriate perioperative provider expertise, or both when feasible.[20]

Baseline Neurological Status and Outcomes

Finally, there are significant controversies that exist around suspension of do-not-resuscitate orders in patients presenting for surgery, as limited data exist on the relationship between preoperative comorbidities and perioperative cardiac arrest survival.[21–23] In the current study, survival to discharge fell steeply with increasing neurologic disability at admission, from 39.6% for those with no major disability, 22.6% for those with moderate disability, 19.6% for those with severe disability, and 6% for those in a coma or vegetative state. Among patients with baseline neurologic deficits, the number of coexisting medical diagnoses did not change survival outcomes. In contrast, among patients with normal baseline neurological status, the total number of coexisting diagnoses was associated with worse survival to discharge and worse survival at 24 h, but the comorbid load bore no apparent relationship with neurological outcome among those surviving to hospital discharge. In other words, the risk of patient harm (facilitating survival, but with new neurologic deficits) is not increased among those patients with normal baseline neurological status, even with an increasing comorbid disease burden. Therefore, the decision to suspend or retain do-not-resuscitate orders in the perioperative period should consider baseline neurological status to a greater degree than the total number of coexisting medical diagnoses. The policy of routinely suspending do-not-resuscitate orders in the perioperative period may not be appropriate for all surgical patients, particularly those who are already in a coma or persistent vegetative state.

Our study findings should be interpreted in the context of the several limitations described in detail previously.[10] First, the registry hospitals may not be representative of all U.S. hospitals and therefore our findings may not be generalizable, although they represent the best summary evidence available. Second, the GWTG-R does not collect certain data that would have been informative for our analyses, including preoperative medications, intraoperative medications, physiologic data, and postoperative interventions. The variables designating cause of arrest were abstracted from the medical record by GWTG-R research coordinators not involved in clinical care of the patient, and therefore, their accuracy has not been validated. The registry does not capture events that do not elicit a hospital response or the use of a crash cart, and thus cardiac procedural and operative arrests may be treated as routine and may not be part of this registry.

In conclusion, one in three patients survived to hospital discharge after perioperative cardiac arrests and two of three survivors had neurologically intact survival. The relatively high rates of survival and good neurological outcomes

following intraoperative and PACU arrests suggest that perioperative factors and immediate availability of skilled anesthesia care have direct influence on improved survival outcomes.

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Appendix 1. Get With The Guidelines-Resuscitation Investigators

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Appendix 2. General Estimating Equation Models to Predict Event Survival with and without Data Imputation for Missing Data

	Preimputation			Postimputation for Missing Data		
Risk Factor	AOR	95% CI	*P* Value	AOR	95% CI	*P* Value
Acute nonstroke neurological event	0.80	0.51–1.26	0.335	0.90	0.55–1.46	0.662
Baseline depression in neurological status	0.65	0.46–0.93	0.018	0.71	0.51–0.98	0.037
Congestive heart failure during admission	0.80	0.57–1.12	0.189	0.74	0.54–1.02	0.065
Hepatic insufficiency	0.64	0.41–1.00	0.051	0.72	0.49–1.06	0.099
Hypotension/hypoperfusion	0.83	0.68–1.01	0.068	0.77	0.64–0.92	0.005
Metastatic or hematologic malignancy	0.94	0.68–1.30	0.714	1.01	0.76–1.33	0.968
Metabolic and electrolyte abnormality	1.17	0.89–1.55	0.263	1.20	0.95–1.52	0.129
Renal insufficiency	1.03	0.83–1.28	0.79	1.03	0.84–1.26	0.804
Respiratory failure	1.13	0.88–1.43	0.337	1.13	0.92–1.40	0.236
Septicemia	0.93	0.65–1.31	0.665	0.90	0.64–1.27	0.558
Active or evolving myocardial infarction	0.64	0.46–0.90	0.009	0.67	0.49–0.92	0.012
Inadequate natural airway	1.25	0.70–2.22	0.446	0.98	0.62–1.55	0.938
Arrhythmia	1.14	0.94–1.39	0.175	1.23	1.04–1.45	0.015
Day hours	1.91	1.47–2.48	<0.001	1.63	1.29–2.04	<0.001
Arrest rhythm (PEA reference value)						
Asystole	1.07	0.85–1.35	0.572	0.99	0.81–1.20	0.901
PVT/VF (shockable rhythms)	1.37	1.02–1.83	0.036	1.23	0.96–1.59	0.106
White *vs.* nonwhite	1.05	0.83–1.32	0.675	0.97	0.80–1.19	0.8
Event location (general in-patient unit—reference)						
Operating room	1.10	0.75–1.61	0.642	1.28	0.88–1.86	0.2
PACU	2.10	1.34–3.29	0.001	2.13	1.42–3.19	0
Telemetry	1.56	0.74–3.26	0.239	1.51	0.77–2.97	0.233
ICU	1.49	0.94–2.36	0.088	1.46	0.94–2.27	0.094
Weekend	0.83	0.64–1.06	0.133	0.84	0.68–1.04	0.117
Invasive ventilation in place prearrest	0.64	0.38–1.08	0.095	0.69	0.50–0.94	0.019
Illness category (medical noncardiac reference value)						
Medical cardiac	1.52	0.94–2.46	0.091	1.57	1.03–2.39	0.035
Surgical cardiac	1.44	0.97–2.15	0.071	1.49	1.05–2.10	0.025
Surgical noncardiac	1.73	1.29–2.33	<0.001	1.45	1.13–1.86	0.003
Trauma	0.75	0.49–1.14	0.181	0.72	0.46–1.15	0.171
Age at hospital admission	0.99	0.99–1.00	0.029	0.99	0.99–1.00	0.003
Duration of event	0.98	0.97–0.98	<0.001	0.98	0.97–0.98	<0.001

AOR = adjusted odds ratio; ICU = intensive care unit areas; PACU = postanesthesia care unit; PEA = pulseless electrical activity; PVT/VF = pulseless ventricular tachycardia or ventricular fibrillation.

Appendix 3. General Estimating Equation Models to Predict Survival to 24 h Postarrest with and without Data Imputation for Missing Data

	Preimputation			Postimputation for Missing Data		
Risk Factor	AOR	95% CI	*P* Value	AOR	95% CI	*P* Value
Acute nonstroke neurological event	0.92	0.62–1.37	0.696	1.00	0.67–1.49	0.995
Baseline depression in neurological status	0.72	0.52–1.00	0.048	0.75	0.54–1.02	0.07
Congestive heart failure during admission	0.99	0.72–1.37	0.969	0.96	0.71–1.29	0.776
Hepatic insufficiency	0.84	0.51–1.37	0.478	0.88	0.57–1.36	0.561
Hypotension/hypoperfusion	0.56	0.46–0.69	<0.001	0.55	0.45–0.67	<0.001
Metastatic or hematologic malignancy	0.81	0.62–1.07	0.132	0.90	0.70–1.17	0.441
Metabolic and electrolyte abnormality	0.75	0.55–1.02	0.062	0.70	0.53–0.93	0.013
Renal insufficiency	1.01	0.81–1.27	0.905	0.98	0.80–1.22	0.888
Respiratory failure	0.91	0.72–1.15	0.427	1.02	0.82–1.26	0.859
Septicemia	0.71	0.49–1.03	0.069	0.66	0.46–0.94	0.02
Active or evolving myocardial infarction	0.62	0.43–0.89	0.01	0.55	0.37–0.81	0.002
Inadequate natural airway	2.37	1.27–4.43	0.007	1.57	1.00–2.48	0.052
Arrhythmia	1.39	1.13–1.71	0.002	1.32	1.09–1.59	0.005
Day hours	1.77	1.29–2.45	<0.001	1.56	1.19–2.05	0.002
White *vs.* nonwhite	1.08	0.86–1.37	0.497	1.02	0.82–1.27	0.853
Arrest rhythm (PEA reference value)						
Asystole	1.08	0.86–1.36	0.497	1.03	0.85–1.25	0.772
PVT/VF (shockable rhythms)	1.35	1.01–1.81	0.042	1.30	1.02–1.66	0.032
Event location (general in-patient unit—reference)						
Operating room	1.18	0.77–1.79	0.448	1.20	0.78–1.82	0.405
PACU	1.76	1.12–2.76	0.015	1.73	1.13–2.65	0.011
Telemetry	0.92	0.47–1.81	0.808	0.90	0.47–1.75	0.761
ICU	0.82	0.52–1.28	0.377	0.74	0.46–1.19	0.21
Weekend	0.67	0.51–0.88	0.004	0.61	0.48–0.77	<0.001
Invasive ventilation in place prearrest	0.42	0.25–0.70	0.001	0.50	0.38–0.67	<0.001
Illness category (medical noncardiac reference value)						
Medical cardiac	1.74	1.03–2.94	0.039	1.62	1.02–2.56	0.041
Surgical cardiac	1.84	1.22–2.78	0.004	1.81	1.24–2.64	0.002
Surgical noncardiac	1.71	1.26–2.31	<0.001	1.42	1.07–1.87	0.015
Trauma	0.31	0.17–0.56	<0.001	0.29	0.17–0.50	<0.001
Age at hospital admission	0.99	0.98–0.99	<0.001	0.99	0.98–0.99	<0.001
Duration of event	0.96	0.95–0.97	<0.001	0.96	0.95–0.96	<0.001

AOR = adjusted odds ratio; ICU = intensive care unit areas; PACU = postanesthesia care unit; PEA = pulseless electrical activity; PVT/VF = pulseless ventricular tachycardia or ventricular fibrillation.

Appendix 4. General Estimating Equation Models to Predict Survival to Discharge in Patients with Pulseless Ventricular Tachycardia or Ventricular Fibrillation Arrests with and without Data Imputation for Missing Data

	Preimputation			Postimputation for Missing Data		
Risk Factor	AOR	95% CI	*P* Value	AOR	95% CI	*P* Value
Acute nonstroke neurological event	0.99	0.47–2.07	0.981	0.99	0.55–1.78	0.979
Baseline depression in neurological status	0.64	0.24–1.69	0.365	0.68	0.31–1.52	0.348
Congestive heart failure during admission	0.58	0.29–1.19	0.137	0.66	0.36–1.18	0.162
Hepatic insufficiency	1.19	0.32–4.48	0.792	0.99	0.32–3.09	0.992
Hypotension/hypoperfusion	0.34	0.22–0.54	<0.001	0.40	0.27–0.60	<0.001
Metastatic or hematologic malignancy	0.83	0.43–1.60	0.569	0.70	0.44–1.13	0.15
Metabolic and electrolyte abnormality	0.56	0.29–1.10	0.095	0.60	0.31–1.16	0.132
Renal insufficiency	0.58	0.35–0.97	0.039	0.52	0.34–0.81	0.004
Respiratory failure	0.72	0.48–1.08	0.111	0.81	0.57–1.15	0.242
Septicemia	0.83	0.32–2.13	0.692	0.65	0.29–1.48	0.308
Active or evolving myocardial infarction	1.21	0.56–2.61	0.636	0.97	0.48–1.98	0.944
Inadequate natural airway	2.15	0.28–16.52	0.461	1.57	0.44–5.66	0.49
Arrhythmia	1.07	0.66–1.76	0.775	1.04	0.70–1.55	0.84
Day hours	1.55	0.83–2.90	0.169	1.48	0.95–2.32	0.084
Event location						
Operating room	2.32	0.82–6.56	0.112	1.75	0.81–3.79	0.158
PACU	2.51	0.85–7.41	0.096	2.05	0.95–4.39	0.066
Telemetry	5.44	0.65–45.79	0.119	5.72	1.10–29.66	0.038
ICU	3.51	1.12–10.95	0.031	1.95	1.06–5.07	0.049
Weekend	0.73	0.38–1.40	0.345	0.63	0.38–1.04	0.071
Invasive ventilation in place prearrest	0.64	0.24–1.68	0.362	0.69	0.36–1.32	0.267
White *vs.* nonwhite	1.32	0.74–2.36	0.346	1.05	0.64–1.70	0.854
Illness category						
Medical cardiac	7.34	2.06–26.13	0.002	3.64	1.52–8.72	0.004
Surgical cardiac	2.30	0.90–5.88	0.083	2.42	1.18–4.95	0.015
Surgical non cardiac	1.66	0.76–3.64	0.204	1.80	1.01–3.20	0.045
Trauma	0.12	0.03–0.48	0.002	0.22	0.07–0.71	0.012
Age at hospital admission	0.97	0.96–0.99	0.001	0.98	0.97–0.99	0.001
Duration of event	0.96	0.94–0.97	<0.001	0.96	0.95–0.97	<0.001

AOR = adjusted odds ratio; ICU = intensive care unit areas; PACU = postanesthesia care unit.

Appendix 5. General Estimating Equation Models to Predict Survival to Discharge in Patients with Asystolic Arrests with and without Data Imputation for Missing Data

	Preimputation			Postimputation for Missing Data		
Risk Factor	AOR	95% CI	*P* Value	AOR	95% CI	*P* Value
Acute nonstroke neurological event	0.70	0.28–1.71	0.428	0.79	0.38–1.63	0.519
Baseline depression in neurological status	0.79	0.38–1.64	0.526	0.95	0.55–1.63	0.847
Congestive heart failure during admission	0.50	0.25–1.00	0.05	0.58	0.32–1.05	0.072
Hepatic insufficiency	0.62	0.24–1.56	0.308	0.73	0.33–1.62	0.435
Hypotension/hypoperfusion	0.31	0.20–0.47	<0.001	0.34	0.24–0.50	<0.001
Metastatic or hematologic malignancy	0.33	0.17–0.62	0.001	0.48	0.29–0.78	0.003
Metabolic and electrolyte abnormality	1.18	0.51–2.71	0.696	0.74	0.36–1.53	0.414
Renal insufficiency	0.77	0.49–1.24	0.284	0.84	0.57–1.24	0.387
Respiratory failure	0.87	0.57–1.34	0.534	1.01	0.71–1.44	0.952
Septicemia	0.31	0.12–0.77	0.012	0.39	0.19–0.80	0.01
Active or evolving myocardial infarction	0.57	0.23–1.43	0.229	0.57	0.23–1.40	0.22
Inadequate natural airway	3.36	0.72–15.72	0.124	3.02	0.92–9.85	0.068
Arrhythmia	1.65	1.17–2.33	0.004	1.60	1.18–2.18	0.003
Day hours	2.31	1.34–3.97	0.003	2.22	1.37–3.59	0.001
Event location						
Operating room	2.52	1.13–5.63	0.024	1.38	1.02–2.58	0.047
PACU	3.36	1.39–8.13	0.007	2.04	1.02–4.09	0.044
Telemetry	0.57	0.13–2.40	0.442	0.59	0.14–2.39	0.456
ICU	0.99	0.39–2.49	0.979	0.60	0.26–1.38	0.228
Weekend	0.54	0.32–0.94	0.028	0.49	0.30–0.79	0.003
Invasive ventilation in place prearrest	0.17	0.07–0.40	<0.001	0.41	0.25–0.67	<0.001
White *vs*. nonwhite	1.35	0.80–2.28	0.264	1.18	0.79–1.75	0.427
Illness category						
Medical cardiac	1.78	0.68–4.69	0.24	1.44	0.61–3.41	0.411
Surgical cardiac	1.03	0.44–2.40	0.947	1.62	0.80–3.29	0.183
Surgical noncardiac	1.88	0.93–3.79	0.078	1.78	1.03–3.08	0.038
Trauma	0.25	0.07–0.93	0.039	0.46	0.17–1.26	0.13
Age at hospital admission	0.98	0.97–0.99	0.003	0.98	0.97–0.99	<0.001
Duration of event	0.95	0.93–0.97	<0.001	0.95	0.93–0.96	<0.001

AOR = adjusted odds ratio; ICU, intensive care unit areas; PACU, postanesthesia care unit.

Appendix 6. General Estimating Equation Models to Predict Survival to Discharge in Patients with Pulseless Electrical Activity Arrests with and without Data Imputation for Missing Data

	Preimputation			Postimputation for Missing Data		
Risk factor	AOR	95% CI	*P* Value	AOR	95% CI	*P* Value
Acute nonstroke neurological event	1.46	0.77–2.78	0.246	1.49	0.77–2.91	0.239
Baseline depression in neurological status	0.68	0.35–1.35	0.275	0.61	0.30–1.23	0.168
Congestive heart failure during admission	0.60	0.32–1.13	0.116	0.68	0.38–1.20	0.184
Hepatic insufficiency	0.64	0.24–1.69	0.364	0.54	0.19–1.51	0.239
Hypotension/hypoperfusion	0.81	0.55–1.19	0.28	0.78	0.52–1.16	0.212
Metastatic or hematologic malignancy	0.70	0.42–1.18	0.183	0.64	0.39–1.06	0.082
Metabolic and electrolyte abnormality	0.53	0.27–1.04	0.063	0.46	0.24–0.89	0.021
Renal insufficiency	0.72	0.49–1.05	0.091	0.66	0.45–0.97	0.033
Respiratory failure	0.81	0.54–1.21	0.299	0.92	0.61–1.40	0.707
Septicemia	0.38	0.16–0.92	0.031	0.32	0.14–0.78	0.011
Active or evolving myocardial infarction	0.09	0.01–0.62	0.015	0.19	0.05–0.69	0.011
Inadequate natural airway	1.91	0.80–4.57	0.144	1.53	0.69–3.39	0.297
Arrhythmia	1.30	0.92–1.82	0.132	1.34	0.98–1.84	0.067
Day hours	1.64	0.80–3.33	0.174	1.52	0.86–2.71	0.153
Event location						
Operating room	0.66	0.28–1.58	0.355	0.52	0.25–1.08	0.079
PACU	1.19	0.47–2.99	0.71	0.89	0.41–1.93	0.773
Telemetry	0.64	0.14–2.91	0.568	0.41	0.09–1.83	0.242
ICU	0.51	0.20–1.32	0.166	0.35	0.15–0.80	0.012
Weekend	0.67	0.37–1.19	0.169	0.49	0.28–0.85	0.011
Invasive ventilation in place prearrest	0.31	0.14–0.70	0.005	0.53	0.32–0.87	0.012
White *vs.* nonwhite	1.07	0.68–1.69	0.769	0.88	0.59–1.32	0.551
Illness category						
Medical cardiac	1.51	0.53–4.31	0.437	1.55	0.64–3.79	0.334
Surgical cardiac	1.99	0.92–4.29	0.08	1.64	0.79–3.38	0.182
Surgical noncardiac	1.31	0.74–2.33	0.351	1.29	0.76–2.19	0.345
Trauma	0.27	0.09–0.79	0.017	0.20	0.07–0.57	0.002
Age at hospital admission	0.98	0.97–0.99	0.001	0.98	0.97–0.99	<0.001
Duration of event	0.96	0.94–0.97	<0.001	0.95	0.94–0.97	<0.001

AOR = adjusted odds ratio; ICU, intensive care unit areas; PACU = postanesthesia care unit.

Appendix 7. General Estimating Equation Models to Predict Good Neurological Outcome in Patients with Good Neurological Status at Admission, before, and after Data Imputation for Missing Data

	Preimputation			Postimputation for Missing Data		
Risk factor	AOR	95% CI	*P* Value	AOR	95% CI	*P* Value
Acute nonstroke neurological event	0.76	0.21–2.75	0.671	1.00	0.27–3.78	0.995
Baseline depression in neurological status	0.69	0.24–2.04	0.504	1.02	0.25–4.13	0.981
Congestive heart failure during admission	1.07	0.38–3.04	0.897	1.09	0.41–2.94	0.857
Hepatic insufficiency	0.66	0.12–3.54	0.627	0.48	0.18–1.27	0.138
Hypotension/hypoperfusion	0.71	0.41–1.23	0.219	0.90	0.59–1.39	0.642
Metastatic or hematologic malignancy	0.75	0.37–1.51	0.417	0.82	0.47–1.44	0.487
Metabolic and electrolyte abnormality	1.55	0.60–3.96	0.363	1.03	0.51–2.07	0.933
Renal insufficiency	0.72	0.35–1.47	0.366	0.73	0.40–1.33	0.311
Respiratory failure	0.88	0.51–1.54	0.658	0.91	0.57–1.46	0.704
Septicemia	0.28	0.08–0.94	0.04	0.43	0.14–1.35	0.146
Active or evolving myocardial infarction	0.96	0.39–2.36	0.929	1.31	0.55–3.15	0.545
Inadequate natural airway	0.44	0.17–1.13	0.087	0.52	0.23–1.18	0.118
Arrhythmia	0.83	0.50–1.37	0.461	0.89	0.58–1.35	0.572
Day hours	1.70	0.70–4.14	0.241	1.09	0.48–2.52	0.831
White *vs.* nonwhite	1.63	0.88–3.02	0.124	1.23	0.72–2.11	0.451
Arrest rhythm (PEA reference value)						
Asystole	0.83	0.43–1.59	0.572	1.09	0.68–1.77	0.718
PVT/VF (shockable rhythms)	1.04	0.55–1.98	0.906	1.07	0.66–1.74	0.773
Event location (general in-patient unit—reference)						
Operating room	5.72	1.75–18.65	0.004	1.66	0.71–3.86	0.242
PACU	5.17	1.62–16.45	0.005	1.88	0.80–4.47	0.15
Telemetry	2.46	0.59–10.21	0.215	0.80	0.21–3.00	0.742
ICU	6.19	1.52–25.25	0.011	1.61	0.51–5.10	0.419
Weekend	1.34	0.58–3.10	0.498	1.20	0.63–2.28	0.578
Invasive ventilation in place prearrest	0.03	0.00–0.29	0.002	0.60	0.33–1.08	0.086
Age at hospital admission	0.98	0.97–0.99	0.005	0.98	0.96–0.99	0.001
Duration of event	0.98	0.97–1.00	0.029	0.98	0.96–0.99	0.001
Illness category (medical noncardiac reference value)						
Medical cardiac	1.23	0.37–4.15	0.733	1.77	0.71–4.43	0.223
Surgical cardiac	1.31	0.43–3.99	0.63	1.50	0.72–3.09	0.276
Surgical noncardiac	1.49	0.59–3.75	0.395	1.44	0.45–4.64	0.536
Trauma	1.16	0.25–5.47	0.853	0.99	0.98–1.00	0.086

AOR = adjusted odds ratio; ICU = intensive care unit areas; PACU = postanesthesia care unit; PEA = pulseless electrical activity; PVT/VF = pulseless ventricular tachycardia or ventricular fibrillation.