# A 20-year experience with urgent percutaneous cardiopulmonary bypass for salvage of potential survivors of refractory cardiovascular collapse

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**Objective:** In-hospital cardiac arrest or refractory shock carries a high mortality despite the use of advanced resuscitative measures. We have implemented an in-hospital, nurse-based, continuously available, percutaneous, venoarterial cardiopulmonary bypass system, also known as extracorporeal life support (ECLS), as an adjunct to resuscitation when initial measures are ineffective.

**Methods:** In 1986, a system for the rapid initiation of ECLS, was created in which trained critical care nurses primed an ECLS circuit and in-house physicians percutaneously placed required cannulas. From a prospective registry, we assessed long-term survival (LTS) (≥30 days, cardiopulmonary support weaned), short-term survival (<30 days, CPS weaned), or death on CPS.

**Results:** One hundred fifty patients (age, 57 ± 17 years) were urgently started on CPS for cardiac arrest (n = 127; witnessed, n = 124; unwitnessed, n = 3) and refractory shock (n = 23). Sixty-nine patients were weaned from CPS, and 81 could not be weaned. Overall, 39 (26.0%) patients achieved LTS with a subsequent Kaplan–Meier median survival of 9.5 years. Duration of CPS was 32 ± 38 hours for LTS and 21 ± 38 hours for non-LTS. LTS occurred in 29 (23.4%) of 124 patients started on CPS for witnessed cardiac arrest and 11 (47.8%) of 23 for refractory shock ($P < .05$). Among patients with CPS initiated in the cardiac catheterization laboratory, LTS was seen in 24 (50.0%) of 48 versus 15 (14.7%) of 102 in patients with CPS initiated in other locations ($P < .001$). Cardiopulmonary resuscitation times greater than or equal to 30 minutes were associated with lower LTS ($P < .05$). The most common cause of death during CPS was refractory cardiac dysfunction (39.5%), and the most common cause associated with short-term survival was neurologic/pulmonary dysfunction (53.6%). Seven patients were bridged to a left ventricular assist device, and 1 subsequently underwent heart transplantation. Multivariate analysis revealed only cardiac catheterization laboratory site of initiation as a significant independent predictor of LTS ($P < .01$). When dividing the 20-year experience in tertiles, recent recipients have had more common prearrest insertion. Rates of long-term survival have not changed.

**Conclusion:** Of patients started on CPS, 46% were weaned, and 26.0% were long-time survivors. Rapid initiation of CPS permits LTS for some inpatients with cardiovascular collapse when initial advanced resuscitation fails. Strategies to improve end-organ function associated with use of CPS should lead to greater LTS. This practical application of inexpensive available technology should be more widely used. (J Thorac Cardiovasc Surg 2010;139:753-7)

Supplemental material is available online.

Despite improvements in techniques of cardiopulmonary resuscitation (CPR), hospitalized patients who undergo refractory shock or cardiac arrest still demonstrate dismal rates of long-term survival. Using standardized criteria,[1] a recent multicenter study in the United States found a survival to discharge after adult in-hospital cardiac arrest of 17%.[2] In patients who require more than 10 minutes of CPR, a 30-day survival of 15.0% has been reported in a single-center report.[3]

In 1954, Gibbon[4] reported the development of a cardiopulmonary bypass system that allowed surgeons to perform complex cardiac repairs for the first time. In 1985, a portable cardiopulmonary support (CPS) system was developed (C. R. Bard, Inc, Billerica, Mass) that could be used with percutaneous catheters, making it possible to implement cardiopulmonary bypass outside the operating room without opening the chest.[4] The extracorporeal system was designed for rapid implementation in patients who would otherwise not survive with refractory cardiac or respiratory failure.

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**Abbreviations and Acronyms**

CNS = central nervous system
CPR = cardiopulmonary resuscitation
CPS = cardiopulmonary support
LTS = long-term survivor
PEA = pulseless electrical activity
VT/VF = ventricular tachycardia/ventricular fibrillation

These techniques have been referred to as extracorporeal life support,[3,5] extracorporeal membrane oxygenation,[6,7] or cardiopulmonary bypass support.[8,9]

In principle, prompt application of CPS could rescue patients with cardiovascular collapse, especially if reversible causes are present[10,11] and neurologic function is preserved.[12] In practice, however, widespread application has been limited.

In 1986, we began a program with a prospective registry of nurse-supported physician initiation of percutaneous CPS that did not initially require a perfusionist. This report reviews our experience with the urgent use of CPS in 150 patients over a 20-year period.

## MATERIALS AND METHODS

This review of patients started on emergency portable CPS at Sharp Memorial Hospital between June 1986 and December 2008 was approved by the Investigational Review Board at Sharp Healthcare.

Patients were selected by the resuscitating physician for emergency CPS when cardiac arrest persisted despite initial advanced cardiac life support or for treatment of refractory shock with imminent cardiac arrest. Patients with CPS support for elective percutaneous cardiac intervention, after a cardiotomy and after failure to wean from conventional bypass, or transferred to our institution after initiation elsewhere were excluded.

Initiation of CPS was accomplished by means of either percutaneous or cut-down placement of cannulas in the femoral or jugular vein (18F–20F) and femoral artery (16F–18F) by using methods previously described.[13] If femoral artery cannulation was associated with distal limb ischemia, then antegrade perfusion was initiated by using methods previously described.[14] Patients undergoing recent cardiac surgery had cannulas placed in central vessels after urgent bedside sternotomy. Treatment was with a BARD (C. R. Bard, Inc, Murrayhill, NJ) hollow-fiber oxygenator in patients 1 to 57 and a heparin-bonded oxygenator (Maxima or Affinity; Medtronic, Minneapolis, Minn) in patients 58 to 150. A Biomedicus (Medtronic, Anaheim, Calif; see Figure E1) centrifugal pump was used in all cases. Before the use of heparin-bonded oxygenators and circuits, activated clotting time was maintained at approximately 300 seconds. With a heparin-bonded oxygenator and circuit, heparin was titrated to an activated clotting time of between 150 and 180 seconds or 120 and 150 seconds if bleeding ensued. Radiographic fluoroscopic guidance was used if immediately available.

Critical care nurses trained in initiation of emergency CPS were responsible for initiation of flow after priming a preassembled centrifugal pump and oxygenator circuit with Isolyte S electrolyte solution (Braun Medical, Irvine, Calif), which is composed of sodium chloride, sodium gluconate, sodium acetate trihydrate, potassium chloride, and magnesium chloride hexahydrate. When cannulation was complete, bypass tubing was connected to the arterial and venous cannulas, and flow was optimized by adjusting the centrifugal pump rotation rate.

Surgical or percutaneous interventions were undertaken if the patient appeared to have a survivable illness and if a remediable cause for cardiac arrest was present. Support was continued until a definitive corrective procedure could be performed, the patient died during bypass, or cardiovascular stabilization permitted weaning from CPS. When possible, weaning from CPS was attempted with gradual reduction of pump flow if mean arterial pressure remained greater than 60 mm Hg on low-dose inotropic support. Most patients required transfusion of packed erythrocytes shortly after initiation of CPS.

### Clinical Data

The national mortality database was queried to obtain long-term dates of death. Demographic information, preclinical conditions, support type, and cause of death were recorded in a prospective registry. Time of CPS initiation was considered routine if between 9 AM and 5 PM Monday through Friday and off hours otherwise. Cardiac rhythms at the time of cardiac arrest and refractory shock were reviewed from computerized hospital records available from the last 8 years. Cardiac causes were specified as coronary (with a history of coronary artery disease), noncoronary, or unknown cardiac. Other causes were specified as either noncardiac or unknown.

### Statistical Analysis

Results are expressed as the mean ± standard deviation. Comparisons were made with a 2-tailed Student $t$ test for continuous variables and Pearson's $\chi^2$ analysis for categoric data. Multivariate logistic regression was performed for long-term survival with SPSS software using variables of sex, age, cause of initiation, time of day, cause of cardiovascular collapse, and location of CPS initiation. From this, a C (convergence) statistic was derived from a receiver operating characteristic curve analysis to assess the predictive accuracy of the regression model. Kaplan–Meier analysis for time to death from the date of long-term survival (≥30 days after initiation) was performed.

## RESULTS

One hundred-fifty patients (103 male and 47 female patients) aged 57 ± 17 years were started on emergency CPS. CPS was initiated for cardiac arrest in 127 patients (124 witnessed and 3 unwitnessed) and refractory shock in 23 patients (including 2 after defibrillation for ventricular fibrillation without CPR). Cannulation was percutaneous in 94, cut-down in 16, open-chest in 30 (after recent cardiac surgery), and not reported in 10 patients (Table 1). Causes of cardiovascular collapse are shown in Table 2.

Overall, 39 (26.0%) patients were long-term survivors (LTS; alive ≥30 days with successful weaning), 30 (20.0%) patients were short-term survivors (alive <30 days with successful weaning), and 81 (54%) patients died on CPS (Figure 1). Long-term survivors had a subsequent Kaplan–Meier median survival of 9.5 years (Figure 2). In patients who were successfully weaned from CPS, 39 (59.4%) of 69 were LTS. Duration of CPS support was 32 ± 38 hours for LTS and 21 ± 38 hours for non-LTSs.

Eleven (47.8%) patients with refractory shock and 29 (23.4%) patients with witnessed cardiac arrest were LTS ($P < .05$, see Figure E2). Three patients with an unwitnessed cardiac arrest died on CPS.

Of 67 patients with available rhythms during cardiac arrest, 45 (67.2%) had pulseless electrical activity (PEA),

**TABLE 1. Demographics for 150 patients started on emergency cardiopulmonary support over the past 20 years**

| | |
|---|---|
| Age (y) | 57 ± 17 |
| Support time (h) | 24.3 ± 38.6 |
| Sex | |
| Male | 103 |
| Female | 47 |
| Indication for extracorporeal life support | |
| Cardiac arrest | 127 |
| Refractory shock | 23 |
| Cannulation | |
| Peripheral, percutaneous | 94 |
| Peripheral, cut-down | 16 |
| Open-chest | 30 |
| Unspecified | 10 |
| Oxygenator | |
| BARD-HF 4000 | 56 |
| Heparin-bonded Maxima | 55 |
| Heparin-bonded Affinity | 39 |

14 (20.9%) had ventricular tachycardia/ventricular fibrillation (VT/VF), and 8 (11.9%) had asystole. Twelve (26.7%) patients with PEA, 6 (42.9%) patients with VT/VF, and 1 (12.5%) patient with asystole were LTS ($P = .31$).

CPR times of 30 minutes or longer were associated with lower long-term survival rates (see Figure E3, $P < .05$). Reasons for prolongation of CPR beyond 30 minutes included intermittent need for CPR, delay in decision making regarding need for CPS, and difficulty in achieving cannulation.

In patients with CPS initiated in the cardiac catheterization laboratory, long-term survival was seen in 24 (50.0%) of 48 versus 15 (14.7%) of 102 with CPS initiated elsewhere than the cardiac catheterization laboratory (critical care unit and other; $P < .001$). In the cardiac catheterization laboratory indication for CPS showed a trend to have an effect on long-term survival. No difference in CPR times in patients undergoing arrest in the cardiac catheterization laboratory versus other locations was observed (Figure 3). Seventeen (45.9%) of 37 patients with cardiac arrest versus 7 (63.6%) of 11 patients with refractory shock who had CPS initiated in the cardiac catheterization laboratory were LTS ($P = .77$).

**TABLE 2. Prearrest cause**

| Cause | Total | Patients achieving LTS | % LTS |
|---|---|---|---|
| Cardiac | 113 | 34 | 31 |
| Coronary cardiac | 86 | 27 | 31 |
| Noncoronary cardiac | 20* | 7 | 35 |
| Unknown cardiac | 7 | 0 | 0 |
| Noncardiac | 32† | 4 | 12.5 |
| Unknown | 5 | 1 | 20 |
| Total | 150 | 39 | 26 |

*LTS*, Long-term survival *Cardiomyopathy (n = 8), transplant rejection (n = 6), myocarditis (n = 2), and ''other'' (n = 4) †Pulmonary embolus (n = 6), amniotic fluid embolism (n = 4), aortic disease (n = 3), septic shock (n = 2), and ''other'' (n = 17).

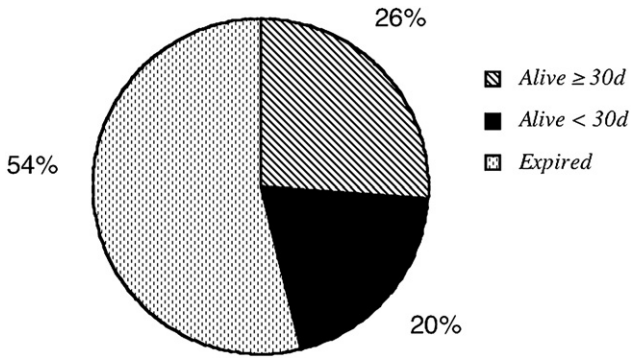


**FIGURE 1.** Distribution of patient survival durations. *Alive <30d*, Weaned from cardiopulmonary support but not long-term survivors; *expired*, death on cardiopulmonary support.

In those who died during CPS, the cause of death was persistent cardiac dysfunction in 32 (39.5%) of 81 patients, whereas 23 (28.4%) patients died of central nervous system (CNS)/pulmonary complications. Fifteen (50.0%) of 30 patients who were short-term survivors (after CPS weaning) died of CNS/pulmonary causes, whereas 6 (20.0%) patients died of persistent cardiac dysfunction ($P = .066$, cardiac vs CNS/pulmonary vs other).

CPS initiation time of day was available for 129 of 150 patients. Seventeen (32.1%) of 53 patients who had CPS initiated between Monday through Friday from 9 AM to 5 PM were LTS compared with 18 (24.0%) of 76 outside of these times. CPS led to left ventricular assist device implantation in 7 (4.7%) patients and subsequent cardiac transplantation in 1 (0.7%) of these patients. When dividing the 20-year experience in tertiles, recent recipients have had more common prearrest insertion (see Figure E4). Rates of long-term survival have not changed over time.

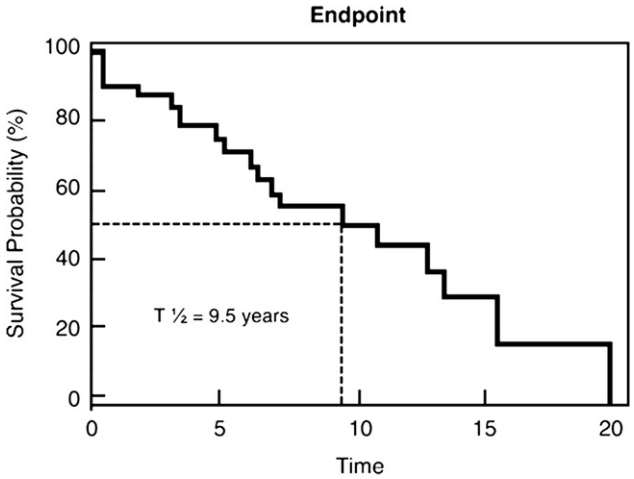


**FIGURE 2.** Kaplan–Meier survival in patients surviving ≥30 days. *T½*, Median survival.

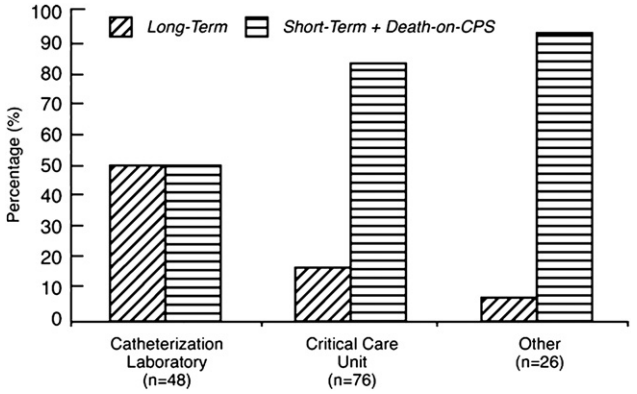


**FIGURE 3.** Survival by location of in-hospital cardiopulmonary support *(CPS)* insertion.

Multivariate logistic regression of long-term survival was conducted by using variables of sex, indication for CPS initiation (refractory shock vs cardiac arrest), age, CPR time, location of CPS initiation, cause of cardiovascular collapse, and time of day. Of these values, only location of CPS initiation was found to be an independent variable predictive of outcome ($P < .01$, see Table E1). Overall, the regression model demonstrated a C statistic of 0.751, indicating a modest value of predictive accuracy.

## DISCUSSION

To our knowledge, this single-center report represents the largest series of consecutive cases of emergency use of CPS for cardiovascular resuscitation of patients refractory to conventional measures. Specifically excluded were patients in whom CPS was initiated for elective-procedure support, those with postcardiotomy failure to be weaned from bypass, and those transferred from an outside hospital. Overall, 26.0% of patients started on CPS were LTS, with a subsequent median survival of 9.5 years. We found the long-term survival rates for refractory shock versus witnessed cardiac arrest to be 47.8% and 23.4%, respectively.

### Indication for CPS

When applied for refractory shock, Combes and colleagues[7] reported a CPS-associated 28-day survival rate of 48%. In patients with persistent cardiac arrest, Chen and associates[3] retrospectively compared outcomes in patients with longer than 10 minutes of conventional CPR who subsequently underwent either CPS (n = 59) or continued conventional CPR (n = 113). Using a propensity score to match potential prognostic factors, there was a significant difference in 30-day survival (hazard ratio, 0.47; 95% confidence interval, 0.28–0.77; $P = .003$) and 1-year survival (hazard ratio, 0.53; 95% confidence interval, 0.33–0.83; $P < .006$),[7] favoring extracorporeal CPS over conventional CPR. CPS 30-day survival was 33.9%, and 1-year survival was 18.6%.[3] Thus CPS is associated with about a 25% long-term survival. Fifty percent of those weaned from CPS are alive 30 days after initiation of support.

Multiple factors could contribute to improved outcomes in the cardiac catheterization laboratory. The cardiac catheterization laboratory environment provides fluoroscopy and availability of adjunctive support equipment. Physician and support staff are present. Alternatively, the cardiac catheterization laboratory site could be a marker for patients with reversible pathologies or better prognoses. There might be less reluctance to initiate CPS support earlier on the part of the physician given the above considerations. No difference in CPR times in patients undergoing arrest in the cardiac catheterization laboratory versus other locations was observed. In a recent report from a multicenter registry of CPS applied for cardiovascular collapse, survival to hospital discharge was 27%. Although initiation of support was not specified, percutaneous cannulation technique was one of the several independent variables predicting survival in a multivariate analysis.[15]

It is uncertain how to replicate outcomes in the cardiac catheterization laboratory for patients in critical care units or other environments. CPS placement could be initiated sooner in patients with rapidly progressive shock before cardiac arrest. Alternatively, patients could be either transported to a cardiac catheterization laboratory environment, or crucial aspects of the cardiac catheterization laboratory environment could be replicated in intensive care units.

Our data suggest that the likelihood for long-term survival with cardiac arrest might be influenced by the associated cardiac rhythm during a cardiac arrest. Although only a trend, patients with VT/VF had long-term survival of 42.9% versus 25% in patients with PEA and 12.5% in patients with asystole. In animal models of ventricular fibrillation, application of CPS improves the subsequent likelihood of cardioversion and survival compared with continued precordial compression and external defibrillation.[16,17] A recent report in 11 patients found that CPS permitted termination of previously refractory ventricular tachycardia.[18]

In the event of cardiac arrest requiring CPR, the decision to use CPS must be prompt because survival is unlikely when CPR extends beyond 30 minutes. Factors that influence the decision to institute CPS should include whether the patient has a remediable underlying disease process. Previous studies support a strategy of CPS as a bridge to implantable left ventricular assist device or heart transplantation in adult patients.[11,19,20] However, only a small portion of our patient population was bridged to other forms of cardiac replacement.

### Cause of Death

In general, after CPS, subsequent death from cardiac causes implies an initial irreversible cardiovascular pathology associated with cardiovascular collapse, whereas death of CNS/

pulmonary causes suggests that CPS was either insufficient or delayed to maintain extracardiac oxygenated blood flow to vital organs. Thus it is not surprising that the primary cause of death in patients who were not weaned from CPS was cardiac. In contrast, among patients who were successfully weaned but were not LTS, cardiac complications were overcome, but neurologic/pulmonary complications were not.

## LIMITATIONS

Conclusions regarding the efficacy of CPS for emergency resuscitation in our series are limited by the lack of a control group. As noted above, although a case–control series with matched patients from a cardiac arrest registry has been reported,[3] a randomized trial would be difficult to achieve. As instrumentation and techniques continue to evolve, registry data might have to suffice for evaluation of the efficacy of CPS for cardiovascular collapse. A uniform patient selection criterion for initiating CPS was not prespecified in this series; however, this allowed assessment in a range of patients more diverse than previous studies. This is a single-center study that cannot be replicated in all centers; it still represents the largest series reported to date. Detailed complication-related data were not acquired for this registry.

## IMPLICATIONS FOR FUTURE IMPROVEMENTS

Rapid application of CPS can temporarily support patients with cardiovascular collapse and permit an assessment of potential options for long-term survival. Before initiation, the likelihood of long-term survival should be considered based on the reversibility of the cause of collapse, the expected duration of CPR, and patient location within the hospital. Translating the results of CPS resuscitation in the cardiac catheterization laboratory to other hospital environments could further improve outcomes for the still-challenging condition of cardiovascular collapse.

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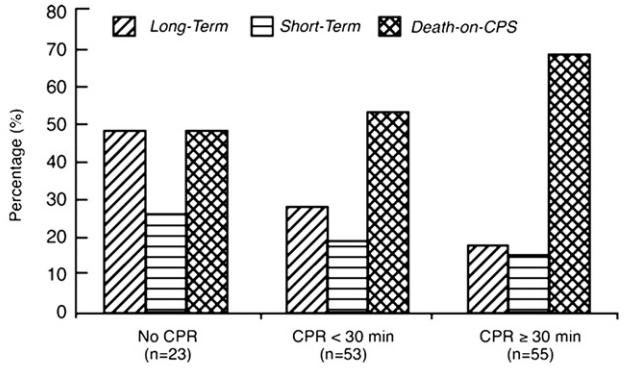
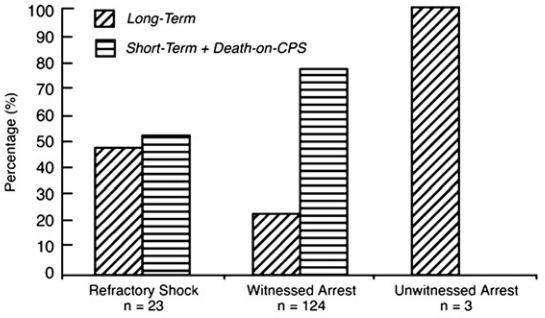
**FIGURE E1.** Cardiopulmonary support cart.




| | | | |
|---|---|---|---|
| Long-term | 47.8 | 28.3 | 18.2 |
| Short-term | 26.1 | 18.9 | 14.5 |
| Death-on-CPS | 26.1 | 52.8 | 67.3 |

**FIGURE E3.** Outcomes ofcardiopulmonary resuscitation *(CPR)* time. *CPS*, Cardiopulmonary support.




| | | | |
|---|---|---|---|
| Long-term | 47.8 | 23.4 | 0 |
| Short-term + Death-on-CPS | 52.2 | 76.6 | 100 |

**FIGURE E2.** Cause of initiation of cardiopulmonary support *(CPS)*.

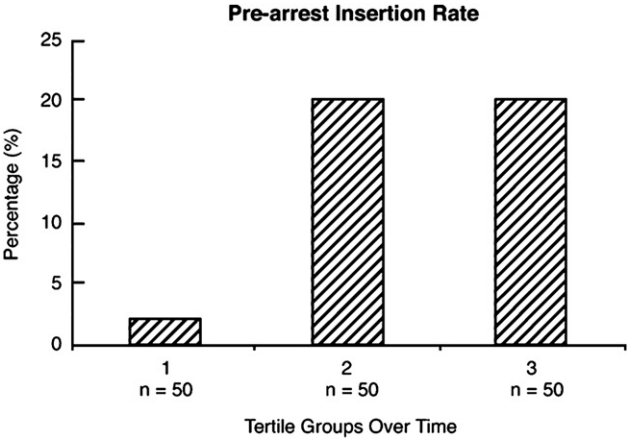



**FIGURE E4.** Prearrest insertion rate.

**TABLE E1. Multivariate analysis**

| Variables | Dummy-coded vectors | B | SE | *P* value | OR | 95% CI |
|---|---|---|---|---|---|---|
| Location | | | | .007 | | |
| | Critical care unit | 1.36 | 0.50 | .007 | 3.90 | 1.45–10.44 |
| | ED/floor/other | 2.37 | 0.92 | .010 | 10.65 | 1.76–64.27 |
| Sex | | –0.25 | 0.49 | .600 | 0.78 | 0.30–2.01 |
| Arrest | | 0.24 | 1.55 | .877 | 1.27 | 0.06–26.46 |
| CPR time | | | | .588 | | |
| | CPR $\leq$29 min | 0.21 | 1.49 | .887 | 1.24 | 0.07–22.81 |
| | CPR $\geq$30 min | 0.49 | 1.53 | .751 | 1.63 | 0.08–32.70 |
| | Unknown | –0.51 | 1.64 | .755 | 0.60 | 0.02–14.96 |
| Age | | 0.02 | 0.01 | .304 | 1.02 | 0.99–1.04 |
| Time/day for implantation | | | | .792 | | |
| | Weekday (9 AM-5 PM) | 0.28 | 0.50 | .579 | 1.32 | 0.50–3.47 |
| | Unknown | –0.12 | 0.65 | .849 | 0.88 | 0.25–3.16 |
| Cause | | | | .655 | | |
| | Cardiac noncoronary | –0.09 | 0.68 | .891 | 0.91 | 0.24–3.47 |
| | Cardiac unknown | 1.45 | 1.31 | .270 | 4.25 | 0.33–55.66 |
| | Noncardiac | 0.64 | 0.69 | .355 | 1.89 | 0.49–7.32 |
| | Unknown | –0.60 | 1.40 | .669 | 0.55 | 0.04–8.56 |

Note: For dummy-coded vectors, the reference groups are as follows (in bold): location **(cardiac catheterization laboratory)**; CPR time **(no CPR)**; time/day for implantation **(weekend or 5 PM to 9 AM)**; and cause **(cardiac coronary)**. *B*, Logit; *SE*, standard error; *OR*, odds ratio; *CI*, confidence interval.