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## Physiologic Monitoring of CPR Quality During Adult Cardiac Arrest: A Propensity-Matched Cohort Study

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### Abstract

**Aim**—The American Heart Association (AHA) recommends monitoring cardiopulmonary resuscitation (CPR) quality using end tidal carbon dioxide (ETCO<sub>2</sub>) or invasive hemodynamic data. The objective of this study was to evaluate the association between clinician-reported physiologic monitoring of CPR quality and patient outcomes.

**Methods**—Prospective observational study of index adult in-hospital CPR events using the AHA's Get With The Guidelines – Resuscitation Registry. Physiologic monitoring was defined using specific database questions regarding use of either ETCO<sub>2</sub> or arterial diastolic blood

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pressure (DBP) to monitor CPR quality. Logistic regression was used to evaluate the association between physiologic monitoring and outcomes in a propensity score matched cohort.

**Results**—In the matched cohort, (monitored n=3032; not monitored n=6064), physiologic monitoring of CPR quality was associated with a higher rate of return of spontaneous circulation ROSC; OR 1.22, CI95 1.04 – 1.43, p=0.017) compared to no monitoring. Survival to hospital discharge (OR 1.04, CI95 0.91 – 1.18, p=0.57) and survival with favorable neurological outcome OR 0.97, CI95 0.75 – 1.26, p=0.83) were not different between groups. Of index events with only ETCO<sub>2</sub> monitoring indicated (n=803), an ETCO<sub>2</sub> >10mmHg during CPR was reported in 520 (65%), and associated with improved survival to hospital discharge (OR 2.41, CI95 1.35 – 4.30, p=0.003), and survival with favorable neurological outcome (OR 2.31, CI95 1.31 – 4.09, p=0.004) compared to ETCO<sub>2</sub> ≤10mmHg.

**Conclusion**—Clinician-reported use of either ETCO<sub>2</sub> or DBP to monitor CPR quality was associated with improved ROSC. An ETCO<sub>2</sub> >10mmHg during CPR was associated with a higher rate of survival compared to events with ETCO<sub>2</sub> ≤10mmHg.

### Keywords

blood pressure; cardiopulmonary resuscitation; heart arrest

## Introduction

In-hospital cardiac arrest affects approximately 200,000 patients each year in the United States.<sup>1</sup> Although outcomes have been improving over the last decade, more than half of adults who have a cardiac arrest during their hospitalization will not survive.<sup>2-4</sup> Many of these arrests now occur in highly monitored intensive care units (ICUs), where patients often have invasive monitoring in place at the time of arrest.<sup>2</sup> A resuscitation strategy that takes advantage of this monitoring and uses it to incorporate a patient's physiologic response into the ongoing resuscitation can be expected to save more lives.<sup>5,6</sup> Experimental literature has established that survival following cardiopulmonary resuscitation (CPR) for cardiac arrest depends on provision of adequate myocardial blood flow.<sup>7-9</sup> However, measurements of myocardial blood flow during CPR are not available to the rescuer. Therefore, the American Heart Association (AHA) now recommends using clinical surrogates closely related to myocardial blood flow (end tidal carbon dioxide (ETCO<sub>2</sub>) or diastolic blood pressure (DBP)) to monitor resuscitation quality.<sup>10</sup> Although the conceptual relevance of hemodynamic and ETCO<sub>2</sub> monitoring during CPR is well established, clinical studies supporting the titration of these parameters during human CPR are lacking.

The primary objective of this study was to evaluate the association between clinician-reported physiologic monitoring of CPR quality using either ETCO<sub>2</sub> or DBP and survival outcomes. We hypothesized that use of physiology to monitor resuscitation quality would be associated with higher rates of return of spontaneous circulation (ROSC). We addressed this hypothesis in a propensity-score-matched cohort study of adult in-hospital CPR events reported to the AHA's large multicenter Get With The Guidelines<sup>®</sup>-Resuscitation (GWTG-R) registry database.

## Methods

The GWTG-R registry is an AHA sponsored prospective multisite database of patients undergoing in-hospital resuscitation that utilizes Utstein-style data reporting.<sup>11-13</sup> Hospitals voluntarily participate in the registry for the primary purpose of quality improvement. The design and reporting of GWTG-R has been described in detail previously ([www.heart.org/resuscitation](http://www.heart.org/resuscitation)).<sup>3,14,15</sup> Quintiles (Cambridge Massachusetts), through their online, interactive case report form and Patient Management Tool (PMT), serves as the data collection coordination center for the AHA/American Stroke Association Get With The Guidelines programs. The University of Pennsylvania acts as the data analytic center and prepares the data for research purposes. Institutional review board (IRB) approval is not required for hospital participation in this quality improvement database; however, the present research investigation was reviewed by the IRB at The Children's Hospital Of Philadelphia and determined to be IRB exempt.

### Cohort Development – Inclusion / Exclusion Criteria

All adult patients (≥ 18 years of age) with a CPR event requiring chest compressions with an invasive airway or arterial catheter in place at the time of arrest were eligible for inclusion. We then subsequently excluded events lasting < 1 minute, any delivery room events, and any events missing either outcome or important confounding variables necessary for propensity matching (Figure 1).

### Study Variables

The primary independent variable was taken from specific questions regarding use of physiologic monitors in the GWTG-R database *optional* section on resuscitation quality (Figure 2). Physiology was deemed to have been used to monitor resuscitation quality if either the following data fields were answered in the affirmative: 1) “Was continuous end tidal CO<sub>2</sub> monitoring used to monitor quality of CPR?” or 2) “Was arterial line diastolic pressure used to monitor compression quality?” In the subset of events in which CPR quality monitoring with ETCO<sub>2</sub> was indicated, we evaluated the association between the level of ETCO<sub>2</sub> achieved during CPR and patient survival. In this analysis, the primary independent variable was ETCO<sub>2</sub> >10mmHg versus ETCO<sub>2</sub> ≤10mmHg<sup>16,17</sup>, the only question specifically asked in the quality section of the GWTG-R registry regarding level of ETCO<sub>2</sub> achieved (“was an end tidal CO<sub>2</sub> value of >10 mmHg achieved?”). The primary outcome for all analyses was ROSC. This acute resuscitation outcome was chosen *a priori* because: 1) it is the most proximate outcome to the monitored CPR (the primary predictor variable); and 2) we prospectively determined that we would be underpowered to detect survival differences between monitoring groups. Therefore, secondary outcomes included survival to hospital discharge and survival to discharge with a favorable neurological outcome. Survival with a favorable neurological outcome was defined as a cerebral performance category (CPC) score of 1, 2 or no change from baseline.<sup>11,15</sup> In accordance with standard Utstein-style definitions<sup>11</sup>, potential confounders were: patient factors, such as demographic characteristics (e.g., race<sup>18</sup>, gender<sup>19</sup>), preexisting conditions, and illness categories; and arrest characteristics, such as interventions in place at time of arrest, first documented rhythm, immediate cause of arrest, time of arrest, duration of CPR, and pharmacologic

interventions (Supplementary Table 1). “First documented rhythm” was defined as the first electrocardiographic rhythm documented during a CPR event. All patients with CPR events regardless of the presence of pulse and rhythm at the onset of CPR were included.

### Statistical methods

The following analysis plan was prospectively developed, and was approved by both the Adult Research Task Force of the AHA’s GWTG-R registry and the Executive Database Steering Committee of the AHA prior to the authors receiving the data for analysis. In this prospective analysis, propensity score matching<sup>20</sup> was used to balance the distribution of potential confounders between patients with versus patients without physiologic monitoring (either ETCO<sub>2</sub> or DBP) at the index event. Propensity scores were estimated as a function of the observed covariates (listed in Supplementary Table 1). For any covariate with missing values, ‘missing’ was coded as a separate category so that the propensity score balanced the distribution of missingness between groups.<sup>21</sup> Propensity score models only included the main effects for covariates because there were no suspected effect modifiers. Participants were matched 2:1 using nearest neighbor matching, with distance based on the log odds. Matching was performed without consideration of outcome values.

Within the matched cohort, standardized mean differences were used to evaluate balance between groups, with balance achieved if the standardized mean difference was <0.10.<sup>22</sup> Logistic regression models were used to compare resuscitation outcomes between matched groups. A robust variance estimator was used to account for the correlation due to clustering of patients within hospitals.<sup>23</sup> In sensitivity analyses, we adjusted for hospital characteristics: trauma level designation, teaching versus non-teaching hospital, urban versus rural location, and presence versus absence of an approved residency program. These sensitivity analyses were limited to hospitals with available data.

### Secondary analyses

In the subset of patients with only ETCO<sub>2</sub> monitoring reported at the index event, we compared patient survival outcomes between events where the reported ETCO<sub>2</sub> was >10mmHg during CPR versus events where the reported ETCO<sub>2</sub> was lower (< 10mmHg) using a logistic regression model with a robust variance estimator to account for within-hospital correlation and adjusted for age, sex, race, patient illness category, night or weekend event<sup>24</sup>, and first documented rhythm.<sup>2,15</sup>

We also evaluated the effect of the release of the 2010 AHA guidelines – which recommended continuous ETCO<sub>2</sub> monitoring during CPR<sup>25</sup>– on the proportion of patients with clinician-reported ETCO<sub>2</sub> monitoring at the index event. The independent variable in these models was 2006 – 2010 period vs. 2011 – 2012. A similar analysis was not completed for DBP monitoring because it was not part of the AHA recommendations until the 2013 CPR Quality Consensus Statement<sup>10</sup>; however, we performed an exploratory analysis to see if the reported use of DBP monitoring changed over time in those patients with an arterial catheter in place at the time of the arrest.

All hypothesis tests were two-sided. All secondary analyses were performed among the unmatched cohort using logistic regression models with a robust variance estimator, as

above. All analyses were completed using R 3.1.1 (R Development Core Team, Vienna, Austria), including the MatchIt and geepack extension packages.

### Data Integrity

To ensure integrity of the data, the GWTG-R registry uses a detailed periodic reabstraction process, whereby participating hospitals submit randomly selected records that are reabstracted and reviewed for errors by the registry's oversight committee. Mean (standard deviation) error rates for all data were 2.5% (2.7%). Remediation through a web-based process to support data integrity was continuously available for all sites. Any new hospitals were certified by testing of the accuracy of their data collection prior to data submission centrally.

## Results

Between January 1, 2006 and September 7, 2012, there were 64,556 index adult CPR events with either an invasive airway or arterial catheter in place at the time of the arrest, of which 23,429 (36%) met inclusion criteria (Figure 1). Of 21,375 index events with an invasive airway in place at the time of the arrest, clinicians reported using ET<sub>CO</sub><sub>2</sub> to monitor quality in 803 (4%). Compared to earlier events, clinician-reported use of ET<sub>CO</sub><sub>2</sub> to monitor resuscitation quality was more common in index events occurring in 2011 and later (5% vs. 3%; OR 1.59, CI95 1.30 – 1.94, p<0.001). Of 7,260 events with an arterial catheter in place at the time of the arrest, clinicians reported using DBP to monitor quality in 2,145 (30%). There was no trend in clinician-reported DBP use over time, which ranged between 25% and 35% per year (p=0.77).

### Physiologic Monitoring of CPR Quality

The propensity score balanced the distribution of potential confounders in the matched cohort of index events (Table 1; monitored n=3,032, not monitored n=6,064), with all standardized mean differences <0.1 (Supplementary Table 1). Clinician-reported physiologic monitoring of CPR quality was associated with higher odds of ROSC (OR 1.22, CI95 1.04 – 1.43, p=0.017) compared to no monitoring with either ET<sub>CO</sub><sub>2</sub> or DBP. Survival to hospital discharge (OR 1.04, CI95 0.92 – 1.18, p=0.57) and survival with favorable neurological outcome (OR 0.97, CI95 0.75 – 1.26, p=0.83) were not different between groups (Table 2).

Of the 334 hospitals that contributed data to this analysis, 262 (78%) had data available on hospital characteristics. In this subset of hospitals, monitoring was associated with increased odds of ROSC (OR 1.23, CI95 1.04 – 1.45, p=0.015). In sensitivity analyses, adjustment for hospital characteristics did not impact the association between monitoring and ROSC (OR 1.22, CI95 1.04 – 1.43, P=0.013).

In the subset of index events with ET<sub>CO</sub><sub>2</sub> CPR quality monitoring indicated (n=803), an ET<sub>CO</sub><sub>2</sub> >10mmHg during CPR was reported in 520 (65%) index events, and was associated with improved survival to hospital discharge (24% versus 11%; OR 2.41, CI95 1.35 – 4.30, p=0.003), and improved survival with favorable neurological outcome (18% versus 8%; OR 2.31, CI95 1.31 – 4.09, p=0.004) compared to index events with ET<sub>CO</sub><sub>2</sub> ≤10mmHg after

accounting for within-hospital correlation and adjusting for age, sex, race, patient illness category, night or weekend event, and first pulseless rhythm.

## Discussion

In this propensity-matched-cohort study of adults using the AHA's multicenter GWTG-R registry, clinician-reported use of physiology to monitor CPR quality with either ETCO<sub>2</sub> or DBP was associated with improved rates of ROSC. Survival to hospital discharge and survival with favorable neurological outcome were not different between groups. In an adjusted model using the subset of 803 index events during which ETCO<sub>2</sub> monitoring was reported as used, an ETCO<sub>2</sub> >10mmHg during CPR was associated with a higher rate of patient survival to hospital discharge and survival with favorable neurological outcome compared to events when ETCO<sub>2</sub> >10mmHg during CPR was not reported. Of note, in the subset of events with an invasive airway in place at the time of arrest, it was not common (4%) for clinicians to report using ETCO<sub>2</sub> to monitor CPR quality.

In a recent consensus statement published in *Circulation*, the AHA now recommends monitoring the patient's physiologic response to the resuscitation effort using ETCO<sub>2</sub> and invasive hemodynamic data.<sup>10</sup> In a hierarchal fashion depending on what is available at the time of the arrest, hemodynamic goals were prioritized over capnography goals. Despite the substantial amount of data that was evaluated in this consensus statement, the authors conceded that clinical studies "supporting the optimal titration of these parameters during human CPR are lacking." Therefore, this study takes an important first step by providing prospectively collected human data and associating clinician-reported intra-arrest physiologic monitoring of CPR quality with superior clinical outcomes.

Numerous experimental models have demonstrated that ETCO<sub>2</sub> correlates well with pulmonary blood flow, cardiac output, and resuscitation success.<sup>17,26–28</sup> Clinical data supporting ETCO<sub>2</sub> monitoring during CPR dates back to the 1970s when Kalenda described using ETCO<sub>2</sub> levels to monitor for rescuer fatigue (declining ETCO<sub>2</sub>) and for ROSC (sudden rise in ETCO<sub>2</sub>).<sup>29</sup> Similarly, but more recently, Sheak et al. demonstrated that CPR quality is associated with ETCO<sub>2</sub> levels during both in- and out-of-hospital resuscitation attempts.<sup>30</sup> Other studies have suggested that ETCO<sub>2</sub> can be used as a prognostic tool during cardiac arrest, as failure to achieve an ETCO<sub>2</sub> of at least 10mmHg is rarely associated with good outcome.<sup>16,17</sup> Similar to these previous reports, we now provide data suggesting that when clinicians monitor resuscitation quality with ETCO<sub>2</sub>, rates of ROSC are higher, and further, than when an ETCO<sub>2</sub> >10mmHg was reported during CPR, rates of survival to discharge and survival with good neurological are also higher.

In the AHA consensus statement, hemodynamic goals were prioritized over ETCO<sub>2</sub> based upon a large body of experimental literature that has established myocardial blood flow as the primary determinant of successful cardiac arrest resuscitation.<sup>7–9</sup> Measures of myocardial blood flow are not easily made available during the resuscitation attempt; therefore, coronary perfusion pressure (CPP; the primary determinant of myocardial blood flow) and arterial DBP (the primary driving force of CPP) were recommended first line as physiologic resuscitation quality monitors because they are most closely related to

myocardial blood flow.<sup>31</sup> Supporting this recommendation, there is also a growing body of pre-clinical evidence demonstrating that titration of CPR efforts to arterial blood pressure can improve survival.<sup>5,6,32</sup> Highlighting a potential limitation of these data, we would have been underpowered to detect an association between *individual* monitoring modalities and outcome in our study cohorts; therefore, we *a priori* chose to define physiologic monitoring as use of either ETCO<sub>2</sub> or DBP. Consequently, further quantitative human investigations are warranted to not only determine the effectiveness of physiologic monitoring to improve survival outcomes, but also which monitor, and further, which physiologic target is most associated with outcome.

The relatively low reported use of physiologic monitoring to guide resuscitation quality deserves comment. Of index events with an invasive airway in place at the time of the arrest, clinicians reported using ETCO<sub>2</sub> to monitor quality in only 803 (4%). Because our dataset was comprised of many events that occurred prior to release of the 2010 AHA guidelines<sup>25</sup>, which recommended the use of ETCO<sub>2</sub> to monitor quality, low rates of clinician reported ETCO<sub>2</sub> monitoring are not surprising. Similarly, among events with an arterial catheter in place, only about 1/3 (30%) of clinicians reported using DBP to monitor CPR quality. DBP monitoring has also not changed significantly over time, likely because all of the index events in the dataset occurred before the release of the 2013 AHA consensus statement which prioritized hemodynamic monitoring.<sup>10</sup> Interestingly, there was an approximately 50% relative increase in the reported use of ETCO<sub>2</sub> to monitor quality at index events that occurred after release of the 2010 guidelines. However, the overall percentage for both still remains low, and suggests that educational efforts to increase physiologic monitoring during resuscitation are warranted.

This study has limitations. First, as with all studies of large multicenter databases, analysis of the data may be limited by data integrity and validation issues due to multiple sites submitting data to the registry. However, the aforementioned rigorous training and certification process, reabstraction data validation processes, and large sample size, which are unique attributes of the AHA GWTG-R registry, minimize these sources of bias. Second, because important confounding post-resuscitation variables<sup>33–37</sup> were not available for the analysis, the effect of physiologic monitoring during CPR on long term survival was not evaluated. Third, actual values of ETCO<sub>2</sub> or DBP, which could have been used to verify the presence of an end tidal or arterial line monitor, and also the level of ETCO<sub>2</sub> achieved during CPR, are not routinely recorded in the GWTG-R database. Next, as the section on CPR quality in the GWTG-R database is optional, generalizability outside of hospitals that report this data may be limited. Fifth, it is worth noting that ventilation rate is an important unmeasured confounder. It is both associated with ETCO<sub>2</sub> levels during human CPR<sup>30</sup> and cardiac arrest survival in animal models<sup>38</sup>, with overventilation associated with mortality. Therefore, the association between higher reported ETCO<sub>2</sub> levels and improved survival may be driven partly by the avoidance of excessive ventilation during CPR. Finally, because only about 15% of hospitals in the US are represented, the generalizability of our findings outside of GWTG-R hospitals remains an unanswered question.

## Conclusions

In this propensity-matched-cohort study of adult in-hospital cardiac arrest using the AHA's GWTG-R registry, clinician-reported use of physiologic monitoring of CPR quality with either continuous ETCO<sub>2</sub> or diastolic blood pressure was associated with an improved rate of ROSC compared to no reported physiologic monitoring. However, survival to hospital discharge and survival with favorable neurological outcome were not different between groups. In the subset of index events where CPR quality was monitored with only ETCO<sub>2</sub>, there were improved rates of patient survival to hospital discharge and survival with favorable neurological outcome when ETCO<sub>2</sub> was reported to be >10mmHg during CPR monitoring. It was not common for clinicians to report the use of physiology to guide resuscitation quality.

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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## Abbreviations

<b>AHA</b>	American Heart Association
<b>CPR</b>	cardiopulmonary resuscitation

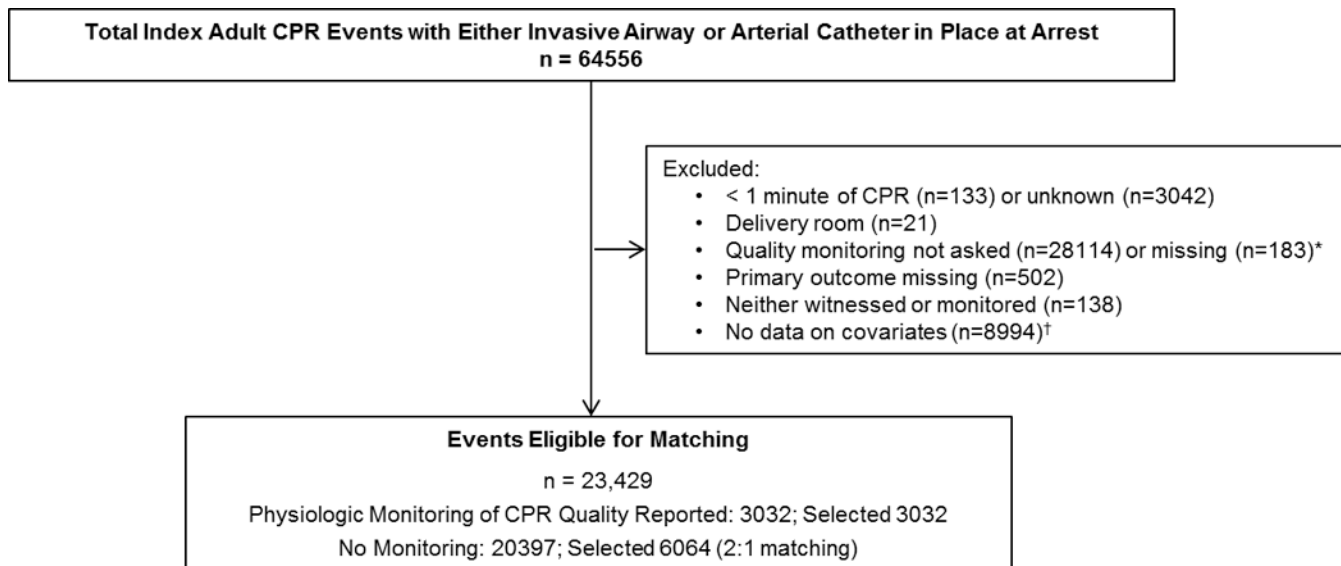
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**Figure 1.**

Consort-like diagram. \*The primary predictor variables were taken from questions added to the data collection form in 2007. †All data for pre-existing medical conditions and cause of arrest were missing which prohibited adjustment for missing in the propensity model as we did with variables with sporadic missingness.

CPA 7.1 CPR Quality	CPR Quality Tab
Was continuous end tidal CO2 monitoring used to monitor quality of CPR?	
<input type="checkbox"/> Yes	
<input type="checkbox"/> No	
<input type="checkbox"/> Not Documented	
If Yes, was an end tidal CO2 value of >10 mmHg achieved?	
<input type="checkbox"/> Yes	
<input type="checkbox"/> No	
<input type="checkbox"/> Not Documented	
Was arterial line diastolic pressure used to monitor compression quality? (Required for pediatric and newborn/neonate patients only)	
<input type="checkbox"/> Yes	
<input type="checkbox"/> No	
<input type="checkbox"/> Not Documented	
<input type="checkbox"/> Not Applicable (arterial line not in place)	

**Figure 2.**  
Get with the Guidelines<sup>®</sup> – Resuscitation Patient Management Tool (PMT), Section 7.1 CPR Quality Tab. Arterial line response is optional for the adult database.

**Table 1**

Characteristics of the study cohort. Summaries presented as median (25th, 75th percentile) or n (%).

	<b>Physiologic Monitoring of CPR Quality</b>		
	<b>Yes*</b> <b>(N=3032)</b>	<b>No, Matched*</b> <b>(N=6064)</b>	<b>No, All</b> <b>(N=20397)</b>
<i>Demographic characteristics</i>			
Age, y	62 (50, 73)	62 (51, 73)	63 (52, 75)
Male sex	1877 (62)	3701 (61)	11824 (58)
Race			
White	1919 (63)	3846 (63)	12643 (62)
Black	687 (23)	1326 (22)	4485 (22)
Hispanic	199 (7)	410 (7)	1427 (7)
Other or unknown	227 (7)	482 (8)	1842 (9)
<i>Pre-existing medical conditions</i>			
Congestive heart failure	480 (16)	957 (16)	2902 (14)
Acute myocardial infarction	553 (18)	1167 (19)	3332 (16)
Arrhythmia	929 (31)	1910 (31)	6167 (30)
Hypotension or hypoperfusion	1559 (51)	2958 (49)	7711 (38)
Respiratory insufficiency	1732 (57)	3524 (58)	11770 (58)
Sepsis or pneumonia	945 (31)	1839 (30)	6689 (33)
Metabolic or electrolyte abnormality	599 (20)	1310 (22)	4112 (20)
Renal insufficiency	1090 (36)	2182 (36)	6947 (34)
Hepatic insufficiency	295 (10)	682 (11)	1966 (10)
Central nervous system depression	354 (12)	711 (12)	2741 (13)
Major trauma	314 (10)	557 (9)	1625 (8)
Cancer	346 (11)	670 (11)	2328 (11)
<i>Characteristics before cardiac arrest event</i>			
Patient illness category			
Medical cardiac	843 (28)	1785 (29)	5840 (29)
Medical non-cardiac	944 (31)	1894 (31)	8836 (43)
Surgical cardiac	440 (15)	898 (15)	1790 (9)
Surgical non-cardiac	525 (17)	1006 (17)	2576 (13)
Trauma	270 (9)	463 (8)	1325 (6)
Other or unknown	10 (<1)	18 (<1)	30 (<1)
Pulse oximeter placement	2948 (97)	5892 (97)	19014 (93)
Electrocardiography monitoring	3006 (99)	6012 (99)	20002 (98)
Arterial catheter placement	2224 (73)	4465 (74)	5481 (27)
Assisted or mechanical ventilation	2410 (79)	4704 (78)	15070 (74)
Vascular access	2992 (99)	5973 (99)	19827 (97)
Vasoactive infusion	1998 (66)	3948 (65)	11023 (54)
<i>Characteristics of cardiac arrest event</i>			
Location of event			

	Physiologic Monitoring of CPR Quality		
	Yes* (N=3032)	No, Matched* (N=6064)	No, All (N=20397)
Intensive care unit	2279 (75)	4516 (75)	13540 (66)
Inpatient monitored	612 (20)	1240 (20)	3868 (19)
Inpatient ward	14 (<1)	33 (1)	422 (2)
Emergency department	85 (3)	183 (3)	2151 (11)
Other or unknown	42 (1)	92 (2)	416 (2)
Night or weekend event <sup>†</sup>	1434 (47)	2882 (48)	10117 (50)
Immediate cause of arrest			
Acute myocardial infarction	248 (8)	526 (9)	1684 (8)
Hypotension or hypoperfusion	1931 (64)	3795 (63)	10843 (53)
Acute respiratory insufficiency	842 (28)	1755 (29)	6572 (32)
Inadequate invasive airway	56 (2)	120 (2)	686 (3)
Acute pulmonary edema	54 (2)	105 (2)	345 (2)
Acute pulmonary embolism	61 (2)	100 (2)	364 (2)
Metabolic or electrolyte abnormality	598 (20)	1322 (22)	3980 (20)
First documented rhythm			
Asystole or pulseless electrical activity	2362 (78)	4615 (76)	15936 (78)
Ventricular fibrillation or tachycardia	576 (19)	1239 (20)	3485 (17)
Number of shocks, #	2 (1, 4)	2 (1, 4)	12 (5, 24)
Bradycardia	21 (1)	43 (1)	104 (1)
Other or unknown	73 (2)	167 (3)	872 (4)
Duration of resuscitation, min	15 (7, 27)	14 (6, 27)	13 (6, 25)
<i>Pharmacologic interventions during arrest</i>			
Epinephrine bolus	2719 (90)	5393 (89)	18408 (90)
Sodium bicarbonate	1797 (59)	3566 (59)	11683 (57)
Calcium chloride or gluconate	1146 (38)	2227 (37)	6542 (32)
Atropine	1889 (62)	3690 (61)	13282 (65)
Fluid bolus	1104 (36)	2115 (35)	6380 (31)
Lidocaine	244 (8)	502 (8)	1383 (7)
Amiodarone	675 (22)	1406 (23)	3949 (19)
Magnesium sulfate	366 (12)	702 (12)	1927 (9)
Dextrose bolus	147 (5)	334 (6)	1032 (5)

\* Each participant with either physiologic monitoring of CPR quality was matched to two participants without monitoring based on a propensity score that included characteristics listed in Table 1 and calendar year. All covariates were balanced within the matched cohorts (all standardized mean differences >0.1; see Supplementary Table 1).

<sup>†</sup>Night: 11:00pm to 6:59am; Weekend: Friday 11:00pm to Monday 6:59am.

**Table 2**

Comparison of resuscitation outcomes among adults with and without monitoring.\*

Outcome	With n (%)	Without n (%)	OR (CI95) <sup>†</sup>	p Value
Return of spontaneous circulation	2117/3032 (70)	3973/6064 (66)	1.22 (1.04, 1.43)	0.017
Survival to hospital discharge	527/3020 (17)	1019/6022 (17)	1.04 (0.91, 1.18)	0.57
Survival with favorable neurological outcome	368/2911 (13)	757/5840 (13)	0.97 (0.75, 1.26)	0.83

OR, odds ratio; CI, confidence interval

\* Each participant with monitoring was matched to two participants without monitoring based on a propensity score that included all variables listed in Supplementary Table 1.

<sup>†</sup> Odds ratios compare the odds of an outcome between index events with versus without monitoring, estimated from a logistic regression model with a robust variance estimator to account for within-hospital correlation.

**Table 3**Comparison of resuscitation outcomes among index events with ETCO<sub>2</sub> monitoring (n=803 index events)

Outcome	ETCO <sub>2</sub> >10mmHg n (%)	ETCO <sub>2</sub> 10mmHg n (%)	OR (CI95)*	p Value
Survival to hospital discharge	125/520 (24)	31/283 (11)	2.41 (1.35, 4.30)	0.003
Survival with favorable neurological outcome	94/520 (18)	23/283 (8)	2.31 (1.31, 4.09)	0.004

OR, odds ratio; CI, confidence interval

\* In the subset of index events with ETCO<sub>2</sub> monitoring indicated, odds ratios compare the odds of an outcome between index events with a reported ETCO<sub>2</sub> >10mmHg versus events with a reported ETCO<sub>2</sub> 10mmHg, estimated from a logistic regression model with a robust variance estimator to account for within-hospital correlation and adjusted for age, sex, race, patient illness category, night or weekend event, and first pulseless rhythm.

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