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RESEARCH REPORT

SONOGRAPHIC CARDIAC ACTIVITY CORRELATES WITH END-TIDAL CARBON DIOXIDE AND CARDIAC RHYTHM IN OUT-OF-HOSPITAL CARDIAC ARREST

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ABSTRACT

Most cardiac arrests that occur in the United States are treated by EMS, which has stimulated interest in the use of prehospital ultrasound as a prognostic tool. Though end-tidal carbon dioxide ($EtCO_2$) and cardiac rhythm have demonstrated prognostic value in out-of-hospital cardiac arrest (OHCA), few studies of ultrasound in the prehospital setting have attempted to address the same question. This retrospective study assesses the association between sonographic cardiac activity and contemporaneous measurements of $EtCO_2$ and cardiac rhythm. Sixty-six cases of paramedic-performed cardiac sonography for OHCA were reviewed and clinical data for each case was abstracted directly from the monitor/defibrillator record. The mean timing of the initial ultrasound was 21 minutes (95% CI [18.7,23.3]) into the resuscitation. Organized cardiac activity was associated with higher mean $EtCO_2$ than absence of organized activity (49.7mmHg (95% CI [44.4,55.0]) versus 28.3mmHg (95% CI [24.3,32.3]), p<0.001). Organized sonographic activity was also associated with contemporaneous cardiac rhythm (p=0.018) and was most frequently observed in pulseless electrical activity with a sinus rhythm. Paramedics interpreted intra-arrest cardiac ultrasound with 95.7% agreement with physicians (κ = 0.940). Mean pause in compressions to acquire ultrasound was 14.9 seconds (95% CI [13.3,16.6]).

INTRODUCTION

Out-of-hospital cardiac arrest (OHCA) is a condition that carries high mortality. Pooled survival after OHCA has been estimated to be 7.6% (Sasson, 2010). There are several patient and system factors that have been associated with survival after OHCA, including initial cardiac rhythm (Sasson, 2010), performance of bystander cardiopulmonary resuscitation (CPR) (Sasson, 2010), emergency medical services (EMS) response time (Holmén, 2020; Huang, 2021), rapid access to automated external defibrillators (AEDs) (Valenzuela, 2000; Caffrey, 2002), witness of the cardiac arrest (Sasson, 2010), end-tidal carbon dioxide ($EtCO_2$) level (Levine, 1997), and duration of CPR (Kim, 2014).

Current data supporting the use of intra-arrest cardiac sonography for prognostication is heterogeneous (Berg, 2020). The presence of organized cardiac activity during resuscitation has been associated with a sensitivity and specificity of survival to hospital discharge of 67-100% and 51-89%, respectively (Atkinson, 2019; Flato, 2015). In contrast, the absence of organized cardiac activity has been associated with a sensitivity and specificity of survival to hospital discharge of 6-91% and 49-94%, respectively (Gaspari, 2016; Varriale, 1997; Zengin, 2016). This wide variability has made it difficult to recommend the use of cardiac ultrasound as the sole criterion to terminate resuscitative efforts. In addition, concerns exist about the impact of ultrasound on CPR pause duration and the potential for disagreements in interpretation.

Since most out-of-hospital cardiac arrests occurring annually in the United States (US) are treated by EMS (Rosamond, 2008), there has been growing interest in the prehospital applications of ultrasound. Of the studies examining cardiac ultrasound in the prehospital setting, most have been primarily focused on feasibility and interrater reliability, though some have demonstrated a correlation between prehospital cardiac activity and patient outcomes (Reed, 2017; Rooney, 2016; Aichinger, 2012; Beckett, 2019).

The primary objective of this study was to assess for associations between sonographic cardiac activity and contemporaneous measurements of end-tidal carbon dioxide and cardiac rhythm in a system where paramedics perform prehospital cardiac sonography for cardiac arrest. The secondary objectives of this study were to assess interrater reliability between paramedic and physician interpreters, and to assess the impact of prehospital sonography on CPR continuity.

METHODS

In Albuquerque, New Mexico, prehospital cardiac sonography has been performed by Albuquerque Fire-Rescue (AFR) paramedics since 2018. When a cardiac arrest is dispatched, a paramedic supervisor in a non-transporting vehicle is included on the initial response alongside first-line units. This small cohort of supervisors has been equipped with a portable ultrasound (Philips Lumify® or GE Vscan®) and special credentialing to perform intra-arrest cardiac sonography. AFR serves a jurisdiction of approximately 189 square miles, and a single EMS supervisor is assigned to each duty period. As such, it is common for the EMS supervisor to arrive on-scene after the arrival of the initial responding units. The use of ultrasound in this system has been investigational, and sonographic assessment is not incorporated into protocols that inform patient care or endpoint of resuscitation. EMS supervisors have been directed to utilize cardiac sonography at their discretion, when doing so would not otherwise impede resuscitation. To limit pause duration, EMS supervisors have been trained to identify an acoustic window with the ultrasound prior to pausing compressions. During the pause, a brief recording is obtained, which can then be reviewed after resuming compressions. The subxiphoid view is customarily used, as this view does not require displacement of plunger-type mechanical CPR devices for image acquisition.

The prehospital medical record was queried to identify all adult, non-traumatic, EMS-treated OHCA during the study period from July 2018 to April 2021. Of this population, records without an attached ultrasound recording were excluded. Patients were also excluded if they were known to be incarcerated, pregnant, or enrolled in the University of New Mexico prehospital extracorporeal CPR program (Marinaro, 2020).

Once the study population was defined, three physician abstractors systematically populated an a priori designated data collection instrument using data from three sources. The data was collected in the Utstein style, except for categories of cardiac rhythm (Nolan, 2019). While the Utstein style describes one category of PEA, this study attempted to discriminate differences between subgroups of pulseless electrical activity (PEA). While there are many possible ways to subcategorize PEA, the decision was made to differentiate subgroups of PEA in this study by the presence of absence of P waves. Patients with an idioventricular rhythm were defined comparably to the Cardiac Arrest Registry to Enhance Survival (CARES), as having a rate less than 40 beats per minute, absent P waves, with a wide (>120ms) or unmeasurable QRS complex.

Demographic data, prehospital interventions, and narrative data were abstracted from the prehospital medical record (ImageTrend, Lakeville, MN). Clinical parameters, including temporal data, vital sign data, and cardiac rhythm were abstracted directly from the resuscitation record stored on the LifePak Monitor/Defibrillator (®Stryker, Kalamazoo, MI) using CODE-STAT™ software. The monitor record was favored over the prehospital medical record for these variables since it enabled abstractors to review objective data to produce a dataset of higher fidelity and completeness. The interval from the start of resuscitation to the initial ultrasound was determined by comparing timestamps from the monitor record and the prehospital medical record. CPR pause durations were calculated by measuring interruptions in the impedance waveform in the monitor record.

Two of the abstractors performed the review of all monitor records using standardized criteria to reduce variation. Ultrasound recordings and paramedic interpretations were stored with the prehospital medical record. All ultrasound recordings were reviewed by the third abstractor, a physician board-certified in Emergency Medical Services.

The study population was characterized using descriptive statistics. The variables chosen to include were those that appear to be associated with OHCA outcomes (Al-Dury, 2020). Categorical variables were reported as proportions and continuous variables were reported as means with 95% confidence intervals. Population differences between subgroups of sonographic activity were assessed by univariate analysis. Proportions of categorical variables were compared with the 2-sided Fischer's exact test. Means of continuous measures were compared with the t-test.

Interrater reliability between the paramedic performing the ultrasound and the physician reviewer was assessed using Cohen's kappa. The timing of the initial ultrasound and length of CPR pause duration was reported as a mean with 95% confidence intervals.

Study data were collected and managed using REDCap electronic data capture tools hosted at the University of New Mexico. All data analysis was performed in SPSS (IBM SPSS Statistics for Windows, version 28.0). The study protocol was approved by the University of New Mexico's Institutional Review Board.

RESULTS

Study Population

During the study period, 70 cases were available for review (Figure 1). Four cases were excluded because of technical limitations in the recorded clips which precluded categorization of sonographic activity. The characteristics of the study population are described in Table 1.

		Overall n=66	Sonographic Activity: Organized n=23	Sonographic Activity: Absent Organized n=43	p
Age Mean [95%CI]		57.7 [43.2,62.2]	52.9 [46.3,59.5]	60.0 [54.0,66.0]	.150
EMS Response Interval Mean [95%CI]		7.5 [6.7,8.3]	7.3 [6.2,8.4]	8.0 [6.2,9.8]	.617
Male %(n)		59.1 (39)	60.9 (14)	58.1 (25)	.830
Witnessed %(n)		42.4 (28)	39.1 (9)	44.2 (19)	.473
Bystander CPR %(n)		51.5 (34)	39.1 (9)	58.1 (25)	.115
Bystander Defib. %(n)		3.0 (2)	0 (0)	4.7 (2)	.539
Initial Presenting Rhythm %(n)	PEA	43.9 (29)	56.5 (13)	37.2 (16)	.381
	Asystole	31.8 (21)	21.7 (5)	37.2 (16)	
	VF	21.2 (14)	21.7 (5)	20.9 (9)	
	VT	3.0 (2)	0 (0)	4.7 (2)	
PEA = Pulseless Electrical Activity, VF = Ventricular Fibrillation, VT = Ventricular Tachycardia					

Table 1. Characteristics of the study population.

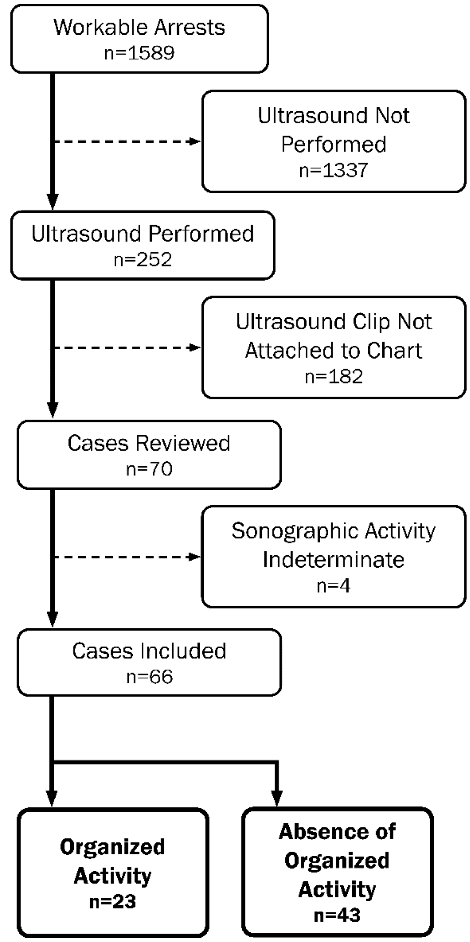

Figure 1: Selection of the study population.

Timing and Duration of Ultrasounds Performed

The mean timing of the initial ultrasound was 21 minutes (95% CI [18.7,23.3]) into the resuscitation. When ultrasounds were obtained, 80.0% (n=53) of them were obtained during a pause in compressions, while 12.1% (n=8) were obtained during a period of ROSC and 7.6% (n=5) were obtained at the time of termination of resuscitation. The mean pause duration when obtaining an ultrasound during resuscitation was 14.9 seconds (95% CI [13.3,16.6]). 34.0% of pause durations were 10 seconds or shorter. In some instances, multiple ultrasounds were performed on a single patient. When only considering the first ultrasound that was performed, the mean pause duration was 14.0 seconds (95% CI [10.3,17.8]). The mean compression fraction and compression rate in the study population were 0.92 (95% CI [0.91,0.93]) and 102.2 (95% CI [102.0,103.0]), respectively.

Interrater Agreement

Interrater agreement between paramedics and physicians was 95.7% for the initial ultrasound ($\kappa = 0.940$).

Association Between Initial Sonographic Activity, End-Tidal Carbon Dioxide, and Cardiac Rhythm

The association between initial sonographic activity and contemporaneous end-tidal carbon dioxide is depicted in Figure 2. Organized cardiac activity was associated with higher mean $EtCO_2$ than absence of organized activity (49.7mmHg (95% CI [44.4,55.0]) versus 28.3mmHg (95% CI [24.3,32.3]), $p<0.001$).

The association between initial sonographic activity and contemporaneous cardiac rhythm was significant ($p=0.018$) and is depicted in Figure 3. Pulseless electrical activity with a sinus rhythm was most associated with organized cardiac activity (65% of cases), and asystole and ventricular fibrillation were least associated with organized cardiac activity (0% of cases for each rhythm). All of the cases of PEA with a sinus rhythm exhibited a narrow QRS interval (<120ms) in the study population.

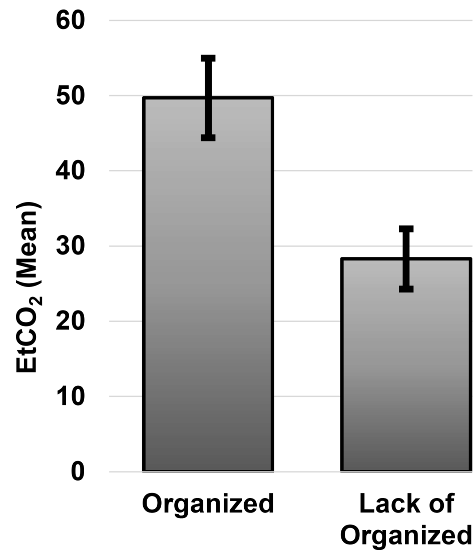

Figure 2: Mean $EtCO_2$ (95% CI) by sonographic activity at time of initial ultrasound.

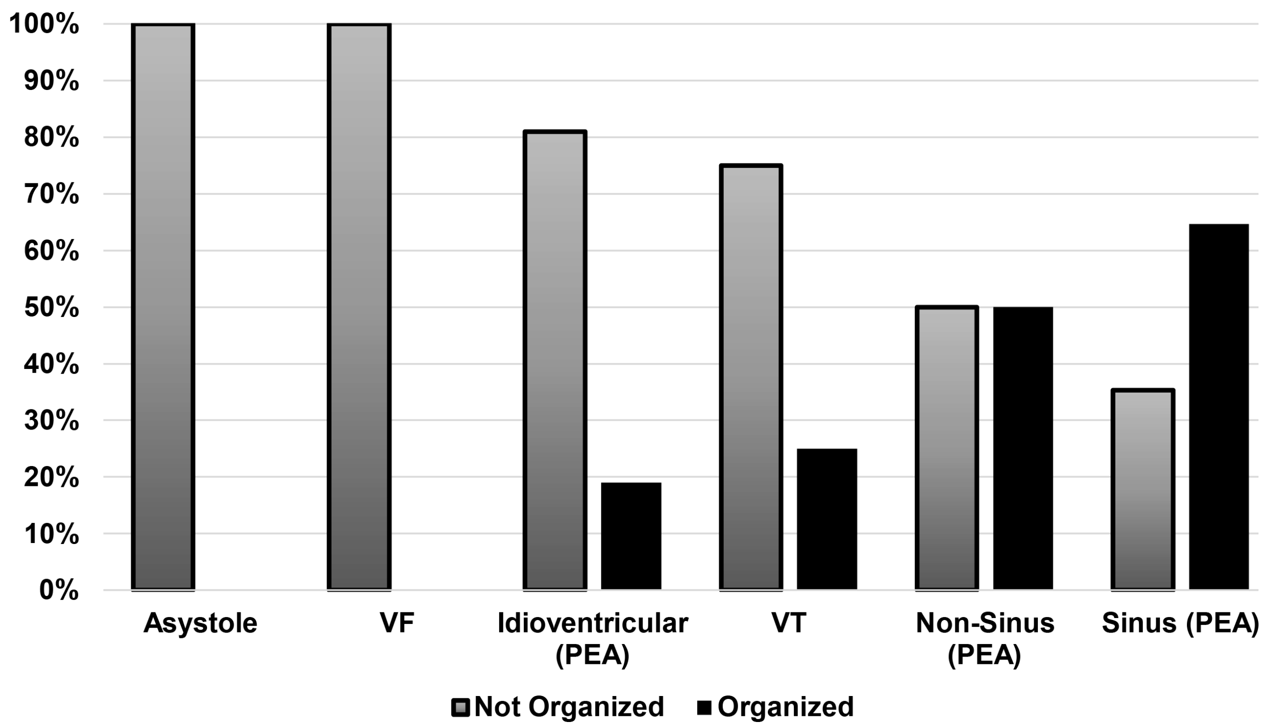

Figure 3: Sonographic activity by cardiac rhythm at time of initial ultrasound. PEA = Pulseless Electrical Activity, VF = Ventricular Fibrillation, VT = Ventricular Tachycardia.

DISCUSSION

In this study, initial sonographic findings correlated with contemporaneous $EtCO_2$ and cardiac rhythm. Though this study was not designed to assess the prognostic value of prehospital sonography due to its retrospective design and non-protocolized inclusion criteria, $EtCO_2$ and cardiac rhythm have demonstrated prognostic value in multiple studies of OHCA (Sasson, 2010; Touma, 2013; Crickmer, 2021; Pokorná, 2010). As such, the observed relationship between sonographic findings and these other variables supports the hypothesis that prehospital sonography may have some prognostic value, although there is a conspicuous absence of prehospital literature that specifically investigates this question. Such studies would be valuable to assess the added utility of prehospital sonography when end-tidal capnography and electrocardiography are already ubiquitous.

When examining the relationship between sonographic findings and PEA, we found that organized cardiac activity was more prevalent when the morphology of the PEA approximated a normal sinus rhythm (defined as having a QRS duration less than 120ms with visible P waves), and less prevalent when the PEA assumed an idioventricular pattern (defined as having a rate less than 40 beats per minute, absent P waves, and a wide and unmeasurable QRS complex). Physiologically, this observation might be explained by the progressive degeneration of both cardiac conductivity and myocardial contractility that occurs in low-flow states. There has been significant heterogeneity in defining PEA in cardiac arrest research, which likely reflects acknowledgment of a phenotypic and prognostic spectrum of disease, which has not been fully typified. Our data support the assertion that more granular definitions of PEA may be useful when attempting to design studies pertaining to OHCA.

We found that organized cardiac activity was associated with higher contemporaneous $EtCO_2$ values. Though the relationship between intra-arrest sonographic findings and $EtCO_2$ has not previously been reported, several studies have indicated that cardiac output directly correlates with $EtCO_2$ (Skulec, 2019; Shibutani, 1994; Weil, 1985; Ornato, 1990; Jin, 2000). Our findings support the supposition that underlying cardiac activity may help explain the observed relationship between $EtCO_2$ and outcomes after cardiac arrest (Sasson, 2010; Touma, 2013; Crickmer, 2021; Pokorná, 2010).

In our system, cardiac sonography for OHCA is successfully performed and interpreted by paramedics with a high degree of physician agreement. In the rare cases in which sonographic activity could not be determined, this was usually related to a four-second limit on recordings imposed by the device. Of the few other studies examining paramedic-performed cardiac sonography, Rooney et al. (2016) reported 100% agreement between US paramedics and physicians board-certified in Emergency Medicine. Of note, there were instances in which sonography was performed without generating a recording. This practice imposes a risk of inflating interrater reliability by biasing the quality of recordings included in the study towards less ambiguous images. Our study also did not measure variation in interpretation between the cadre of EMS supervisors, although there were a small number of individuals in this group.

In our study, the mean elapsed time until the initial ultrasound was performed was 21 min (95% CI [18.7,23.3]). The elapsed time observed in this study is likely a reflection of the need to perform priority resuscitative measures and may also be related to the prolonged response time of the EMS supervisor. Due to small sample sizes, this study did not examine relationships between contemporaneous clinical variables and the timing of the ultrasound, which might be useful when attempting to discriminate a niche for ultrasound.

Eighty percent of ultrasounds were obtained intra-arrest and the mean pause duration associated with the use of ultrasound was 14.9 seconds (95% CI [13.3,16.6]). It is not known whether these durations were significantly different from pauses in which ultrasound was not used, though the overall chest compression fraction and compression rates in this population were excellent. When ultrasound was performed, 34.0% of pause durations were 10 seconds or shorter. In comparison, in the population studied by Reed et. al. (2017), 44% of pause durations were 10 seconds or shorter.

Although there were 1589 workable cardiac arrests occurring during the study period, only 4.4% (n=70) received cardiac sonograms by the EMS supervisor. There are multiple potential explanations for this observation. In addition to the challenges of operating a single vehicle for such a large response area, EMS supervisors do not attend to all dispatched cardiac arrests. In the absence of strict protocolization for ultrasound use, there is also a likely selection bias imposed by the EMS supervisor, whereby ultrasound is employed on certain patients in whom there is a perceived benefit. Though this limits the usefulness of the data for assessing patient outcomes, there is still value in exploring these potential biases. For example, the percentage of patients presenting with PEA in our study population was 43.9%, as compared to 12-30% in other studies (Väyrynen, 2008; Bergström, 2018). Similarly, only 31.8% of patients in the study population presented with asystole. It is reasonable to surmise that cardiac sonography would have limited utility in a patient presenting with asystole, which may have been reflected in patient selection.

Strengths of our study include abstraction of data directly from the monitor record, the use of a small cadre of trained physician reviewers, and a standardized data abstraction process, all of which improved the fidelity of the data. Several limitations of this study are related to its retrospective design. Most notably, because the application of ultrasound was not protocolized, the study population was impacted by selection bias by the ultrasound operators. This bias prohibited the use of these data to draw conclusions about patient outcomes. Additionally, only a small percentage of eligible cardiac arrest cases had an ultrasound recording performed. Though selection may play a role, there is also the potential for exclusion bias. For example, if an ultrasound operator attempted to acquire an ultrasound image and the image quality was poor, they might elect not to save the recording. The decision to place ultrasound onto the paramedic supervisor units may also have impacted enrollment. Though these units are dispatched to all cardiac arrests in the city, their response times are often lengthy compared to first-line units. As such, it is common for first-line units to cancel the response of the paramedic supervisor when ROSC has already been achieved or the patient is determined to be non-viable. This practice imposes a survivorship bias on the study population, whereby early survivors are often excluded from the dataset.

Future studies would ideally employ a prospective design with strict protocolization of ultrasound use to limit selection and exclusion biases. The decision to place ultrasound on first-line units may help minimize survivorship bias, but the cost of interference with resuscitation must be considered. Future studies might also benefit from the study of a particular subgroup of patients in cardiac arrest, especially those with PEA.

CONCLUSIONS

Among patients with out-of-hospital cardiac arrest, organized cardiac activity is associated with pulseless sinus rhythms and higher $EtCO_2$. Paramedics can perform and interpret intra-arrest cardiac ultrasound with a high degree of agreement with physicians. The performance of intra-arrest cardiac ultrasound is associated with modest prolongation of compression pause duration beyond 10 seconds.

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