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ORIGINAL RESEARCH

Emergency Medical Services

Metrics of mechanical chest compression device use in out-of-hospital cardiac arrest

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Abstract

Objective: The quality of cardiopulmonary resuscitation (CPR) affects outcomes from cardiac arrest, yet manual CPR is difficult to administer. Although mechanical CPR (mCPR) devices offer high quality CPR, only limited data describe their deployment, their interaction with standard manual CPR (sCPR), and the consequent effects on chest compression continuity and patient outcomes. We sought to describe the interaction between sCPR and mCPR and the impact of the sCPR-mCPR transition upon outcomes in adult out-of-hospital cardiac arrest (OHCA).

Methods: We analyzed all adult ventricular fibrillation OHCA treated by the Anchorage Fire Department (AFD) during calendar year 2016. AFD protocols include the immediate initiation of sCPR upon rescuer arrival and transition to mCPR, guided by patient status. We compared CPR timing, performance, and outcomes between those receiving sCPR only and those receiving sCPR transitioning to mCPR (sCPR + mCPR).

Results: All 19 sCPR-only patients achieved return of spontaneous circulation (ROSC) after a median of 3.3 (interquartile range 2.2–5.1) minutes. Among 30 patients remaining pulseless after sCPR (median 6.9 [5.3–11.0] minutes), transition to mCPR occurred with a median chest compression interruption of 7 (5–13) seconds. Twenty-one of 30 sCPR + mCPR patients achieved ROSC after a median of 11.2 (5.7–23.8) additional minutes of mCPR. Survival differed between groups: sCPR only 14/19 (74%) versus sCPR + mCPR 13/30 (43%), $P = 0.045$.

Conclusion: In this series, transition to mCPR occurred in patients unresponsive to initial sCPR with only brief interruptions in chest compressions. Assessment of mCPR must consider the interactions with sCPR.

1 | INTRODUCTION

1.1 | Background

The quality of the cardiopulmonary resuscitation (CPR) provided to victims of out-of-hospital cardiac arrest (OHCA) affects their chances of survival. Real-world manual chest compressions suffer from poor quality: compressions are often too shallow, administered at incorrect rates, and frequently interrupted.[1,2] Mechanical CPR (mCPR) devices deliver chest compressions with consistent depth and rate, full recoil, and high compression fraction.

1.2 | Importance

The use of mCPR involves not only the device but also its application, entailing positioning of the device back plate under the patient, connection and adjustment of compression mechanism, and actuation of the device. Most important, application of the mCPR device must be coordinated with ongoing resuscitation efforts entailing standard manual CPR (sCPR). The time and manner of device application may potentially influence resuscitation quality and outcomes. Neither the large randomized controlled trials (RCTs) nor the majority of observational trials on mCPR devices report or analyze these important parameters.[3-13] A detailed analysis of a small subset of cases in 1 RCT revealed that the median pause in CPR for device deployment was over 30 seconds.[14]

1.3 | Goals of this investigation

We sought to describe the interaction between sCPR and mCPR and the impact of the sCPR-to-mCPR transition upon resuscitation of adult OHCA.

2 | METHODS

2.1 | Study design and setting

The study is a retrospective analysis of out-of-hospital ventricular fibrillation (VF) cardiac arrests treated by the Anchorage Fire Department (AFD). The University of Alaska Anchorage Institutional Review Board reviewed the study and found it not to be human subject research and to be exempt from further oversight.

The AFD provides all 911 emergency medical service (EMS) responses and transports for the Municipality of Anchorage, Alaska, a community of 300,000. A cardiac arrest response is initiated by dispatch with concurrent telecommunicator CPR and is attended by a minimum of 5 professional EMS responders, at least 2 of whom are paramedics. As part of a broader program of high-performance CPR, mCPR devices have been used by AFD since 2007.[15,16] Resuscitated patients are preferentially taken to tertiary care hospitals with 24-hour access to interventional cardiology and typical intensive care treatment including routine targeted temperature management.

2.2 | Selection of subjects

We included all adult VF OHCA receiving sustained CPR by AFD during 2016. We excluded patients with Do Not Resuscitate orders and those for whom the defibrillator's electronic record was unavailable.

2.3 | Interventions

During this study, 15 LUCAS 2 Chest Compression Systems (Stryker/Jolife AB, Lund, Sweden) were carried by Advanced Life Support (ALS) vehicles. CPR provided by the AFD typically starts with 2-minute cycles of manual CPR, sometimes followed by transition to the mCPR device, a decision made by the lead paramedic. The decision on whether to use mCPR is dynamic and includes such parameters as patient size, initial response to treatment such as transient return of spontaneous circulation (ROSC) suggesting that the event may successfully terminate early, and other scene considerations. Protocols allow for scene termination and transport with mCPR in progress is uncommon but occurs occasionally.

The AFD applies mCPR devices following a strict protocol that is reinforced by frequent in-station training. All members adhere to the tenet of minimizing the interruption in chest compressions to apply the device; recordings of the monitor-defibrillator impedance signal are routinely reviewed to determine whether this pause has met the goal of being < 10 seconds. The AFD incorporates the use of mCPR into its high-performance CPR training with weekly in-station training.

2.4 | Outcomes and measurements

The primary outcomes were (1) duration of sCPR, and (2) duration of CPR interruption for transition to mCPR; these measures were abstracted from continuous ECG and transthoracic impedance recordings from the monitor-defibrillator (LIFEPAK 12 or LIFEPAK 15, Physio-Control, Redmond, WA, USA). We differentiated sCPR from mCPR by identifying the differences in impedance morphology characteristic of sCPR and mCPR (Figure 1). Two investigators (BMH and DY) used CODE-STAT 10.0 Advanced CPR Analytics software (Physio-Control, Redmond, WA, USA) to analyze these recordings

independently, then resolved discrepancies through consensus discussion. We defined the sCPR-to-mCPR transition as the duration from the last manual compression to the first mechanical chest compression.

Secondary outcomes include ROSC and survival to hospital discharge. ROSC was defined as the restoration of a sustained palpable pulse, and the point in time at which it occurred was determined by an event marker and cessation of CPR. Survival was defined as alive vital status upon discharge from the hospital. The patient's discharge neurological status was defined using the cerebral performance category (CPC) scoring method at the time of discharge.

Other variables used in the analysis included patient characteristics (age, sex), arrest characteristics (location, witnessed status, cardiac cause, type of bystander CPR/automated external defibrillator use prior to AFD arrival, who initiated CPR), resuscitation characteristics (advanced airway, resuscitation drugs, out-of-hospital therapeutic hypothermia) and response times.

2.5 | Analysis

We divided the cohort into 2 groups: (1) sCPR-only, patients who received only manual CPR, and (2) sCPR + mCPR, patients who transitioned to mCPR after initial standard CPR. Because the AFD protocol requires that all resuscitations begin with standard manual CPR, there were no cases that received only mCPR. We compared patient characteristics between sCPR-only and sCPR + mCPR. We determined the elapsed time of sCPR, the interruption in CPR for transition from sCPR to mCPR, and the duration of subsequent resuscitation. We compared outcome between sCPR-only and Scpr + mCPR using Fisher's exact test.

3 | RESULTS

3.1 | Characteristics of study subjects

During the study period, AFD treated 248 OHCA, including 53 (21%) presenting with VF/ventricular tachycardia (VT). We excluded 3 patients with pre-existing Do Not Resuscitate orders and 1 who received neither CPR nor defibrillation, leaving 49 in the analysis: 19 sCPR-only and 30 sCPR + mCPR.

The patients included in our analysis were 56 (51–65) years old; 63% were male. The cardiac arrests were of cardiac cause in most (92%), were witnessed in most (80%), and occurred in a home or residence in the majority (69%) of patients.

3.2 | Comparison of sCPR-only and sCPR + mCPR groups

Compared to sCPR-only, sCPR + mCPR patients were less likely to experience OHCA in a public setting and had CPR initiated less often by a layperson. Other characteristics of patients and arrests did not differ between groups.

> **The Bottom Line**
>
> Although prior studies describe cardiac arrest outcomes with the use of mechanical cardiopulmonary resuscitation (CPR) devices, few have described the details of the coordination between standard manual and mechanical chest compressions. This series of 49 adult out-of-hospital cardiac arrests from Anchorage, Alaska provides detailed perspectives of the complex transition from standard manual to mechanical chest compressions. These findings highlight the intricacies of studying mechanical chest compressions, including the potential influence of resuscitation time bias.

The duration of manual CPR and the total duration of CPR were both significantly longer in the sCPR + mCPR group than the sCPR-only group (Figure 2, Table 2). The response to CPR differed significantly between groups even before device application. All sCPR-only patients achieved ROSC, doing so after 3.3 (2.2-5.1) minutes of manual CPR. Patients in the sCPR + mCPR group remained pulseless through 6.9 (5.3–11.0) minutes of manual CPR; the 21 sCPR + mCPR patients who got ROSC did so after 11.2 (5.7–23.8) additional minutes of CPR, delivered by the mCPR device (Figure 3).

Among the 30 patients who transitioned to mCPR, the transition occurred in a median of 7 (5–13) seconds (Figure 2). The longest interruption in chest compressions for any reason was slightly longer for sCPR + mCPR than sCPR-only: 14 (10–19) versus 10 (7–12) seconds, $P = 0.007$. sCPR + mCPR patients received more resuscitation medications and defibrillation shocks than sCPR-only did (Tables 1 and 2). Time to ED arrival and time on scene were longer in the sCPR + mCPR group.

Overall, 73% of the VF/VT patients survived to hospital admission. Survival to admission differed between the sCPR-only and sCPR + mCPR; 18/19 (95%) versus 18/30 (60%), $P = 0.008$. Overall, 55% survived to hospital discharge. Survival to hospital discharge differed between the sCPR-only and sCPR + mCPR: 14/19 (74%) versus, 13/30 (43%), $P = 0.045$ (Table 1).

4 | LIMITATIONS

This study is relatively small because it focuses on VF/VT cardiac arrests instead of including all arrests, and it limits enrollment to a single EMS system and a single year. Because of the small sample size, we did not perform multivariate risk adjustment. These results reflect performance at a single EMS agency and may not generalize to other systems. The AFD system, where this study took place, allows 5 personnel on scene and, by protocol, does at least 2 cycles of manual CPR before deciding whether to apply the mCPR device. These and other factors, such as whether resuscitation may be terminated in the field and whether the system transports with ongoing CPR, can all be
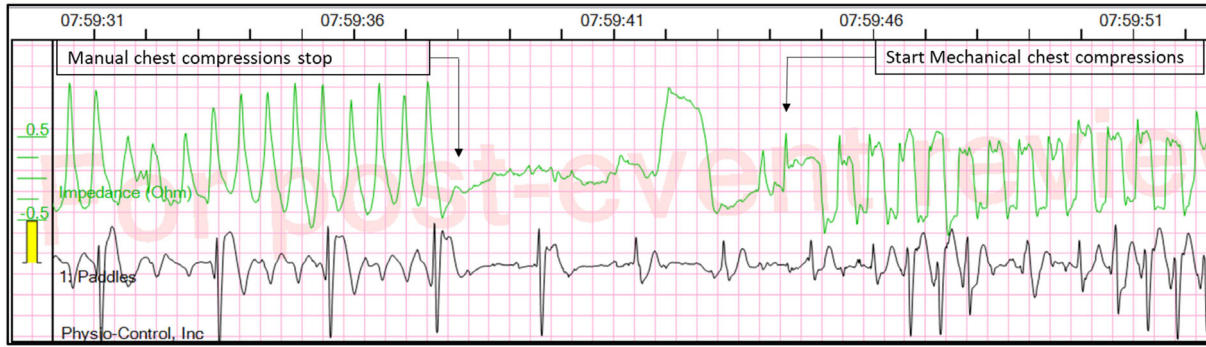
FIGURE 1 Monitor/defibrillator data from a patient with pulseless electrical activity following defibrillation showing a 22-second interval during which the cardiopulmonary resuscitation (CPR) transitioned from manual chest compressions to mechanical chest compressions with a pause in compressions of about 6 seconds. Figure illustrates change in impedance morphology on transition to mechanical chest compressions, with waveforms becoming more square and having a consistent, precise rate. The top green curve shows the transthoracic impedance signal; the bottom black curve shows the ECG. Time format is HH:MM:SS.
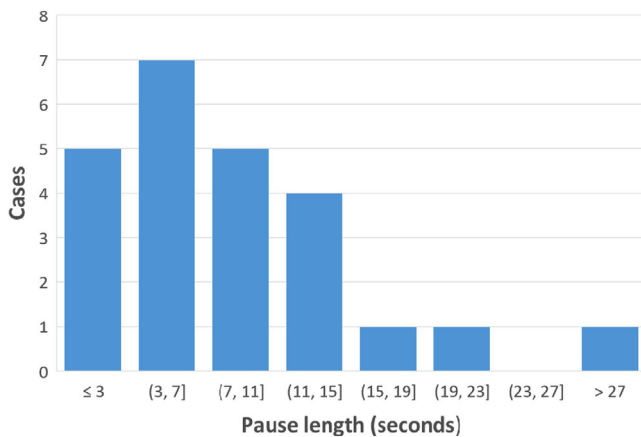

FIGURE 2 Histogram of the length of the interruption of chest compressions for application of the mechanical compression device to the patient. The patient in the far-right bin had an interruption time of 28 seconds. Data are missing for 6 patients; in 1 case the device was placed prior to connection of the defibrillator electrodes and in 5 cases the impedance channel was unavailable.

FIGURE 3 Overview of cardiopulmonary resuscitation (CPR) timing and clinical outcome, with 1 row for each patient in the final analysis group, showing the durations of manual CPR (yellow) and mechanical CPR (mCPR; black) from the start of CPR until either first return of spontaneous circulation or termination of resuscitation. Patients in the standard manual CPR (sCPR)-only group received only manual chest compressions; patients in the sCPR + mCPR group transitioned from manual chest compressions to mechanical chest compressions. Vertical (red) dashed lines show median manual CPR time for sCPR-only and sCPR + mCPR groups. ED, emergency department; ROSC, return of spontaneous circulation.

expected to influence the details of device use and the relationship between device use and clinical outcomes. We did not include children in the analysis.

5 | DISCUSSION

In this study we characterized the interaction of sCPR and mCPR, determining the resuscitation duration before transitioning from sCPR to mCPR as well as the duration of CPR interruption necessary to transition from sCPR to mCPR. Our findings highlight some important perspectives on mCPR device use and post event analysis and provide new understanding that is helpful in interpreting previous studies of these devices.

We found important differences in resuscitation time course between patients with manual CPR and patients receiving manual and
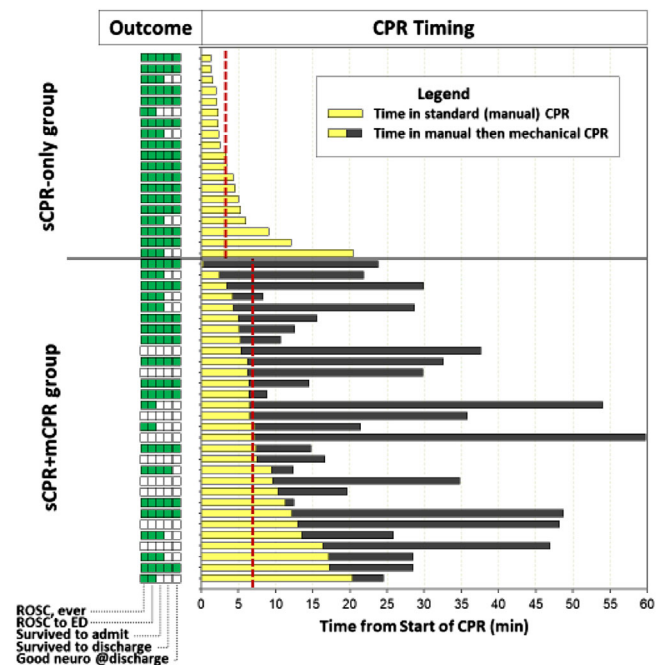
then mCPR. In retrospect, the patients who received only manual CPR were patients who responded quickly to resuscitation efforts and, by definition, were easier to resuscitate. They had more favorable circumstances surrounding their initial care; their CPR was started more often by a layperson, and chest compressions were started significantly

TABLE 1 Characteristics of cardiac arrests, resuscitation attempts, and outcomes

Cardiac arrest related parameters (N [%])	All (N = 49)	sCPR-only (N = 19)	sCPR + Mcpr (N = 30)	P
Witnessed	39 (80%)	17 (89%)	22 (73%)	0.28
Cardiac cause	45 (92%)	18 (95%)	27 (90%)	>0.99
Out-of-hospital therapeutic hypothermia	37 (76%)	15 (79%)	22 (73%)	0.74
Who initiated CPR (N [%])				
Layperson	38 (78%)	18 (95%)	20 (67%)	0.03
Family member	29 (59%)	12 (63%)	17 (57%)	0.77
First responder	2 (4%)	0 (0%)	2 (7%)	0.52
Responding EMS personnel	8 (16%)	1 (5%)	7 (23%)	0.13
Physician or nurse	3 (6%)	2 (11%)	1 (3%)	0.55
Location of arrest (N [%])				
Home/residence	34 (69%)	11 (58%)	23 (77%)	0.21
Health facility	2 (4%)	1 (5%)	1 (3%)	> 0.99
Public building/place of recreation/industrial/transport center	9 (18%)	7 (37%)	2 (7%)	0.02
Street/highway	3 (6%)	0 (0%)	3 (10%)	0.27
Type of bystander CPR/AED (N [%])				
Chest compressions only	37 (76%)	17 (89%)	20 (67%)	0.09
Chest compressions and ventilation	2 (4%)	1 (5%)	1 (3%)	> 0.99
Unknown	9 (18%)	1 (5%)	8 (27%)	0.13
Dispatch assisted CPR	37 (76%)	15 (79%)	22 (73%)	0.74
AED use prior to EMS	5 (10%)	2 (11%)	3 (10%)	> 0.99
Advanced airway (N [%])	41 (84%)	15 (79%)	26 (87%)	0.69
Oral/nasal endotracheal tube	30 (61%)	13 (68%)	17 (57%)	0.55
Laryngeal Mask Airway/King Airway	11 (22%)	2 (11%)	9 (30%)	0.16
Impedance threshold device (ITD)	45 (92%)	17 (89%)	28 (93%)	0.64
Resuscitation-related drugs used (N [%])	37 (76%)	7 (37%)	30 (100%)	< 0.001
Epinephrine	32 (65%)	4 (21%)	28 (93%)	< 0.001
Amiodarone	21 (43%)	2 (11%)	19 (63%)	< 0.001
Sodium bicarbonate	16 (33%)	1 (5%)	15 (50%)	0.001
Other drugs used	18 (37%)	8 (42%)	10 (33%)	0.56
Time variables (mm:ss and Median [Q1-Q3])				
Time from arrest to first chest compressions	03:11 [02:07-05:30]	03:03 [02:00-03:59]	04:27 [02:51-05:55]	0.06
Time from arrest to call	01:00 [01:00-02:00]	01:00 [00:34-02:00]	01:00 [01:00-02:00]	0.37
Time from arrest to first responder on scene	06:44 [05:44-07:48]	06:15 [05:46-07:04]	07:01 [05:44-07:59]	0.51
Time from arrest to ambulance on scene	07:49 [06:19-09:35]	07:15 [05:46-09:21]	08:09 [07:00-09:55]	0.22
Time from arrest to EMS at patient side	09:00 [07:44-10:55]	09:30 [06:46-10:38]	08:53 [07:58-11:40]	0.57

(Continues)

TABLE 1 (Continued)

Cardiac arrest related parameters (N [%])	All (N = 49)	sCPR-only (N = 19)	sCPR + Mcpr (N = 30)	P
Time from arrest to ambulance left scene	33:27 [26:57-37:24]	29:39 [25:36-34:48]	36:18 [28:49-45:32]	0.04
Time from arrest to emergency department arrival	41:06 [33:36-49:24]	37:12 [32:08-41:37]	44:41 [36:55-54:23]	0.01
Outcome parameters (N [%])				
Return of spontaneous circulation (ROSC) anytime	40 (82%)	19 (100%)	21 (70%)	0.008
Survived to hospital admission, all VF/VT	36 (73%)	18 (95%)	18 (60%)	0.008
Discharged alive, all VF/VT	27 (55%)	14 (74%)	13 (43%)	0.045
Good cerebral performance, CPC 1	23 (47%)	13 (68%)	10 (33%)	0.02
Moderate disability, CPC 2	3 (6%)	1 (5%)	2 (7%)	> 0.99
Severe disability, CPC 3	1 (2%)	0 (0%)	1 (3%)	> 0.99
Discharged alive, witnessed VF/VT	23/39 (59%)	12/17 (71%)	11/22 (50%)	0.32

CPC, cerebral performance category; EMS, emergency medical services; AED, automated external defibrillator; VF/VT, ventricular fibrillation/ventricular tachycardia; CPR, cardiopulmonary resuscitation; mCPR, mechanical CPR; sCPR, standard manual CPR.
Characteristics of cardiac arrests, parameters of resuscitation attempts, and outcomes for patients presenting with VF/VT treated during 2016 by the Anchorage Fire Department (All), and for subgroups of patients receiving only manual chest compressions (sCPR-only) and patients receiving manual chest compressions followed by mechanical compressions (sCPR + mCPR).

sooner after their arrest (in 3.1 vs 4.5 minutes). These patients who received only manual CPR got ROSC relatively quickly, after receiving a median of 3.3 minutes of manual CPR. In contrast, the patients who received mCPR were those who failed to get ROSC during manual CPR (median 6.9 minutes) and then received mCPR, intravenous drugs, and additional defibrillation shocks as part of their more prolonged resuscitation attempts. We were also able to objectively demonstrate that mCPR device use did not appreciably affect the chest compression fraction in those patients, eliminating one potential cause of the decreased survival rate in the sCPR + mCPR group.

In general, the probability of favorable outcome from cardiac arrest is known to decrease as the duration of the resuscitation attempt increases; patients most likely to survive regain a pulse within the first few minutes, whereas less viable patients often remain pulseless through many minutes of CPR.[17-19] Consequently, therapies to treat pulselessness applied later in the resuscitation will necessarily be applied to patients with lower chances of survival, giving rise to "resuscitation time bias" tending to make these therapies appear potentially harmful in results of observational studies.[20] For example, in our study, survival is significantly lower in the sCPR + mCPR group than in the sCPR-only group, a difference that would be consistent with resuscitation time bias; the decision to apply the device was not made until the patient had remained pulseless through at least 2 cycles of CPR. Because of factors that tend to delay use of mCPR devices until after the initial minutes of resuscitation, this same bias likely affects the results of the many observational studies that have attempted to compare manual and mCPR; unfortunately, this cannot be confirmed because these studies did not measure or report timing metrics.[7-13]

Three RCTs conducted between 2008 and 2013 compared manual and mechanical chest compression in OHCA; primary end points of those trials found that survival was similar for manual CPR and mCPR.[3-5] Since then, much has been learned about how to monitor and optimize use of the devices, but those improvements have not yet been tested in a randomized controlled trial. A new randomized trial should compare care with and without mechanical chest compressions, with particular attention to pitfalls related to the 2 time metrics on which our study focused: interrupting chest compressions for too long when applying the device and using the mCPR device too early or too late in the resuscitation. In the previous RCTs, the mCPR devices were applied as early as possible rather than initially focusing on high-quality manual basic life support (BLS), and the interruptions in compressions to apply the devices were over 30 seconds in the few patients for whom this metric was reported.[3-5,14] Detailed review of monitor data, as we have done in this study, would serve to confirm and provide feedback on these important aspects of care.

This study demonstrates that mechanical chest compression device application times can and should be measured to reinforce minimizing chest compression interruptions. When to apply the device can be controlled by protocol to capitalize on early BLS success while also placing it in a time frame when the patient is still potentially viable. The timing of device application should be considered when interpreting observational studies of outcomes of patients who did and did not receive mechanical chest compressions, realizing that mCPR devices are used primarily on patients requiring prolonged resuscitation attempts, which are known to be independently associated with worse outcome.

TABLE 2 CPR intervals, chest compression parameters, and defibrillation parameters

	All (N = 49)	sCPR-only (N =19)	sCPR + mCPR (N= 30)	P
Time in manual CPR	6.0 [3.4-9.4]	3.3 [2.2-5.1]	6.9 [5.3-11.0]	< 0.001
Time in mechanical CPR	NA	NA	13.2 [7.6-26.5]	NA
Total time in CPR min	14.5 [4.6-28.5]	3.3 [2.2-5.1]	25.2 [15.0-34.2]	< 0.001
CPR times for patients achieving ROSC (minutes, Median [Q1-Q3])				
Time in manual CPR	5.1 [2.9-8.8]	3.3 [2.2-5.1]	6.8 [4.8-11.9]	0.006
Time in mechanical CPR	NA	NA	11.2 [5.7-23.8]	NA
Total time of CPR	11.6 [3.8-23.9]	3.3 [2.2-5.1]	22.3 [12.5-28.8]	< 0.001
CPR times for surviving patients (minutes, Median [Q1-Q3])				
Time in manual CPR	5.0 [2.6-7.4]	3.4 [2.1-5.1]	6.4 [5.1-10.4]	0.01
Time in mechanical CPR	NA	NA	8.4 [4.2-24.9]	NA
Total time in CPR	9.1 [3.3-14.8]	3.4 [2.1-5.1]	14.8 [12.5-29.2]	< 0.001
When did ROSC occur? (N [%])				
After only EMS CPR and defibrillation shocks	15 (31%)	14 (74%)	1 (3%)	<0.001
After ALS	25 (51%)	5 (26%)	20 (67%)	0.009
Never	9 (18%)	0 (0%)	9 (30%)	0.008
Chest compression parameters (Median [Q1-Q3])				
Interruption in chest compression for device deployment 7 (5-13)	NA	7 [5-13]	NA	
Longest chest compression interruption during the resuscitation attempt (s)	12 [9-16]	10 [7-12]	14 [10-19]	0.007
Compression fraction (%)	95 [93-96]	94 [92-98]	95 [93-96]	0.86
Compression rate cc/min	106 [102-119]	121 [110-128]	102 [102-109]	< 0.001
Defibrillation parameters (Median [Q1-Q3])				
Number of shocks (N)	3 [1-4]	1 [1-2]	4 [3-5]	< 0.001
Time from start of manual chest compressions to first shock (mm:ss)	01:18 [00:34-02:11]	00:47 [00:18-01:54]	01:25 [00:54-02:12]	0.074
Pre shock compression interruption (s)	4 [3-6]	4 [3-8]	3 [3-6]	0.74
Post shock compression interruption (s)	0 [0-1]	0 [0-1]	0 [0-0]	0.43

CPR, cardiopulmonary resuscitation; EMS, emergency medical services; ALS, advanced life support; ROSC, return of spontaneous circulation; NA, not applicable; sCPR, standard manual CPR; VF/VT, ventricular fibrillation/ventricular tachycardia.

Chest compression parameters, CPR intervals, and defibrillation parameters for patients presenting with VF/VT treated during 2016 by the Anchorage Fire Department (All) and for subgroups of patients receiving only manual chest compressions (sCPR-only) and patients receiving manual chest compressions followed by mechanical compressions (sCPR + mCPR).

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