Resumption of Chest Compressions After Successful Defibrillation and Risk for Recurrence of Ventricular Fibrillation in Out-of-Hospital Cardiac Arrest

Zacherie Conover, BS; Karl B. Kern, MD; Annemarie E. Silver, PhD; Bentley J. Bobrow, MD; Daniel W. Spaite, MD; Julia H. Indik, MD, PhD;

Background—Prior investigation of out-of-hospital cardiac arrest has raised the concern that ventricular fibrillation (VF) recurrence may be triggered by chest compression (CC) resumption. We investigated predictors of VF recurrence after defibrillation, including timing of CC resumption.

Methods and Results—Patients with witnessed out-of-hospital cardiac arrest and initial rhythm of VF from an Utstein-style database were analyzed. For each shock that defibrillated VF, CC resumption and VF recurrence times were determined. Shocks were classified according to postshock rhythm. Factors (age, sex, time from dispatch to monitor/defibrillator application, and CC resumption) that could predict VF recurrence were analyzed. CC resumption was categorized into groups: CC1, 1 to 5 seconds; CC2, 6 to 10 seconds; CC3, 11 to 30 seconds; and CC4, >30 seconds. Eighty-eight subjects were analyzed, with a total of 285 shocks, with 226 shocks that achieved asystole (n=102), organized rhythm (n=120), and monomorphic ventricular tachycardia (n=4). After a successful shock, CC resumption occurred at a median (interquartile range) of 8 (5–18) seconds. VF recurred after 166 shocks (74%) and recurred within 30 seconds in 69 shocks. There was no significant relationship between VF recurrence and factors analyzed including CC resumption time, nor stratified by postshock rhythm. The hazard ratios (HRs) for VF recurrence within 30 seconds for later CC groups (CC2, CC3, and CC4) relative to early CC resumption (CC1) were as follows: HR(CC2)=1.05 (P=0.9); HR(CC3)=1.75 (P=0.1); and HR(CC4)=0.67 (P=0.4).

Conclusions—VF recurrence within 30 seconds of a defibrillatory shock was not dependent on timing of CC resumption in patients with witnessed arrest and initial rhythm of VF. (Circ Arrhythm Electrophysiol. 2014;7:633-639.)

Key Words: cardiopulmonary resuscitation • heart arrest • ventricular fibrillation

During the past 10 years, the cardiopulmonary resuscitation (CPR) guidelines for the treatment of ventricular fibrillation (VF) have been modified to increasingly emphasize the delivery of chest compressions (CCs) by increasing the ratio of CC to ventilation, limiting the number of shocks to 1 rather than 3 stacked shocks and increasing the duration of CC between shocks from 1 to 2 minutes.1–4 In parallel to these changes, the survival for VF arrest has improved. In 2010, the survival to hospital discharge for cardiac arrest with witnessed VF in the Resuscitation Outcomes Consortium database was 28.4%,4 increased from prior estimates of 17.7%.3 CCs are further emphasized in CC–only CPR for bystanders and cardiocerebral resuscitation for emergency medical personnel, which has resulted in a further improvement in survival for witnessed cardiac arrest attributable to VF, rising ≤33.7% in Arizona.6

Despite these improvements in survival during the past several years, there has remained the concern that CC may trigger the recurrence of VF. VF recurrence is common during resuscitation,7–11 and the triggers are unclear. In an analysis of cardiac arrest survivors in the Netherlands,12 it was found that VF was highly likely to recur within the first 2 seconds after the reinitiation of CC, regardless of whether CCs were resumed immediately after the shock or delayed for a postshock rhythm analysis. Another investigation of cardiac arrest survivors in Rochester, MN,13 suggested that the risk of VF recurrence during CC was related to the postshock rhythm, finding that VF was more likely to recur during CC delivered to postshock asystole.

We have investigated predictors for VF recurrence after defibrillation, including timing of CC resumption in a cohort of witnessed cardiac arrest survivors in Arizona with initial rhythm of VF. Our hypothesis was that the risk of VF
recurrence in the first 30 seconds postshock is unrelated to when CCs are resumed.

Methods
Resuscitation data from adult patients with witnessed out-of-hospital cardiac arrest (OHCA) were collected through the Saving Hearts in Arizona Registry and Education (SHARE) Program, a previously described statewide Utstein-style database. OHCA has been designated as a major public health problem by the Arizona Department of Health Services. SHARE is the designated public health program created to measure response to OHCA and improve outcomes. Thus, the SHARE Program initiatives and its data collection are exempt from the Health Insurance Portability and Accountability Act. By virtue of SHARE being a health department–sponsored public health initiative, the Arizona Department of Health Services’ Human Subjects Review

Figure 1. Monitor/defibrillator recording including cardiopulmonary resuscitation (CPR) bars for chest compressions (CCs). The third shock results in an organized rhythm (first strip), and CCs are resumed 12 seconds later as evidenced by CC artifact and immediately followed by the onset of CPR bars (second strip). The CPR filter is immediately applied, giving a filtered ECG (second strip), and ventricular fibrillation recurrence is seen ≈16 seconds after CC resumption (fourth strip). Recording was exported using RescueNet Code Review (ZOLL Medical Corporation). HR indicates heart rate; MFC, multi-function cable; and PR, pulse rate.
Board and the University of Arizona institutional review board have determined that neither the interventions nor their evaluation constitute human subjects research and have approved the publication of deidentified data.

Data for this investigation were taken from 2 sites in Arizona participating in the SHARE Program from 2008 through 2011. The details of the methodology for data collection in the SHARE database have been described previously. Inclusion criteria were OHCA with resuscitation initiated in the field. Exclusion criteria included age <18 years, unwitnessed arrest, or initial rhythm other than VF. Return of spontaneous circulation was defined as a confirmed pulse for ≥5 minutes. Cardiac waveforms were downloaded from the defibrillator (ZOLL Medical Corporation) and inspected using RescueNet Code Review (ZOLL Medical Corporation). Analysis of shock outcome was made at 5 seconds after the shock. Shocks that successfully defibrillated VF were further classified as an organized rhythm (OR) if ≥2 QRS complexes were present and otherwise as asystole. A shock outcome of ventricular tachycardia (VT) was made if a wide complex monomorphic tachycardia was present at 5 seconds postshock. Defibrillation of VF was considered successful if VF was terminated for ≥5 seconds after shock delivery, whereas the presence of polymorphic VT (or VF) was regarded as a failure of defibrillation. Resumption of CCs was identified by CPR artifact and the presence of ≥3 seconds of uninterrupted CPR bars, derived by the defibrillator from the accelerometer signal (Figure 1). Time to CC resumption postshock was further categorized to 4 prespecified CC groups: 1 to 5 seconds (CC1), 6 to 10 seconds (CC2), 11 to 30 seconds (CC3), and >30 seconds (CC4). Shock outcome and time to resumption of CCs were determined by 2 observers (Z.C. and J.H.I.). The ECG waveform was filtered for CPR artifact by the manufacturer’s software (ZOLL Medical Corporation) to allow visualization of the underlying rhythm, and time to recurrence of VF was determined by 1 observer (J.H.I.). Excluded were cases with significant artifact that obscured the underlying rhythm including loss of pad contact after the shock. Figure 1 shows an example of an ECG recording that includes filtering and the determination of CC resumption and VF recurrence.

Statistical Analysis

Continuous variables are presented as the median with interquartile range (25th–75th percentile). Statistical tests were performed using STATA (StataCorp, College Station, TX). Simple linear regression

**Table 1. Patient and Resuscitation Characteristics**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>88</td>
</tr>
<tr>
<td>Age, y</td>
<td>64 (53–71)</td>
</tr>
<tr>
<td>Women, %</td>
<td>23</td>
</tr>
<tr>
<td>Cardiac cause, %</td>
<td>95</td>
</tr>
<tr>
<td>Time from dispatch to monitor/defibrillator connection, min</td>
<td>6.5 (5.5–8.1)</td>
</tr>
<tr>
<td>No. of shocks</td>
<td>285</td>
</tr>
<tr>
<td>Shocks/patient</td>
<td>3 (1–4)</td>
</tr>
<tr>
<td>Compressions/min</td>
<td>112 (101–125)</td>
</tr>
<tr>
<td>Compression depth, in</td>
<td>2.0 (1.8–2.3)</td>
</tr>
<tr>
<td>Subjects with prehospital ROSC</td>
<td>41</td>
</tr>
<tr>
<td>Subjects with survival to hospital admission</td>
<td>52</td>
</tr>
<tr>
<td>Subjects with survival to hospital discharge</td>
<td>34</td>
</tr>
</tbody>
</table>

**Shock outcome**

- Ventricular fibrillation: 59
- Ventricular tachycardia: 4
- Asystole: 102
- Organized rhythm (not ventricular tachycardia): 120

**CC resumption, s**

- All shocks: 8 (5–14)
- For shocks that defibrillate VF: 8 (5–18)
- Ventricular fibrillation recurrence post shock, s: 39 (16–120)

CC indicates chest compression; and ROSC, return of spontaneous circulation.

*Median (25th–75th percentile).
analysis was used to analyze factors that could be associated with the time to VF recurrence after a successful defibrillatory shock for patients with VF recurrence, with a logarithmic transformation of the time to VF recurrence. Factors analyzed were age, sex, time from Emergency Medical Services dispatch to connection of the monitor/defibrillator, and time to CC resumption after the shock. In addition, the analysis was stratified with respect to shock outcome of asystole or OR. Generalized linear mixed models using random effects were used to account for correlations within an individual subject attributable to multiple shocks.

A Kaplan–Meier analysis with proportional hazards model was performed to examine the risk of VF recurrence in the first 30 seconds postshock, according to CC group; correlations within the same subject for multiple shocks were accounted for using the cluster option within STATA and Efron’s method to handle ties. Subjects were also classified according to whether there was any shock followed by VF recurrence within 30 seconds; differences in proportions between any VF recurrence within 30 seconds and outcome (prehospital return of spontaneous circulation [ROSC], survival to hospital admission, or survival to hospital discharge) were assessed with a $\chi^2$ analysis.

**Results**

A total of 88 adult witnessed OHCA cases with initial rhythm of VF from the SHARE database were analyzed, with a total of 285 shocks, median of 3 shocks per patient, range of 1 to 11 (interquartile range: 1–4), and 226 shocks that successfully defibrillated VF (Figure 2). One subject was excluded for an uncertain postshock rhythm (fine VF versus asystole in the presence of CC) and another subject in whom the pads were not in contact immediately postshock. Prehospital ROSC was achieved in 41 subjects, survival to hospital admission in 52 subjects, and survival to hospital discharge in 34 subjects. The first shock successfully defibrillated VF in 76 of 88 subjects, whereas second and later shocks defibrillated VF 76% of the time. Rearrest with VF after achieving ROSC was seen in 10 subjects, with VF recurring in a range from 1 to 17 minutes after ROSC was documented, with a median of 4 minutes and 45 seconds. Compression rate was 112 (101–125) compressions/min with a compression depth of 2.0 (1.8–2.3) in. Of 226 successful shocks, VF recurred after 166 (74%) shocks, after 39 (16–120) seconds postshock, and within 30 seconds in 69 shocks. Patient and resuscitation characteristics are given in Table 1.

After a successful shock, CC resumption occurred at 8 (5–18) seconds postshock. Numbers of successful shocks by CC group were as follows: CC1, CC2, CC3, CC4=59, 60, 56, 51, respectively (Table 2). Figure 3 compares the time of VF recurrence with CC resumption for shocks where VF subsequently recurs. Time of VF recurrence and CC resumption within the first 60 seconds postshock distinguishing first and subsequent shocks is shown in Figure 3B.

Of the 226 shocks that defibrillated VF, 102 (45%) shocks resulted in asystole and 120 (53%) shocks to an OR other than monomorphic VT and 4 (2%) shocks to monomorphic VT (Figure 2). VF recurred at 47 (24–135) seconds after 78 shocks that had resulted in asystole and recurred at 32 (14–76) seconds after 84 shocks that had resulted in an OR other than monomorphic VT (Figure 3C). The time to CC resumption was 9 (6–13) seconds after shocks that resulted in asystole and 8 (4–21) seconds after shocks that resulted in an OR other than monomorphic VT.

There was no statistically significant difference in the time to VF recurrence according to age, sex, or time from Emergency Medical Services dispatch to connection of the

| Table 2. Early VF Recurrence (<30 seconds postshock) by CC Group |
|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|
|                         | CC1 (1–5 s) | CC2 (6–10 s) | CC3 (11–30 s) | CC4 (>30 s) | Total |
| No. of successful       | 59          | 60          | 56           | 51          | 226   |
| defibrillatory shocks   |             |             |              |             |       |
| VF recurrence by 30 s, n (%) | 17 (29)    | 17 (28)    | 25 (45)      | 11 (22)     | 70 (31) |

CC indicates chest compression; and VF, ventricular fibrillation.
monitor/defibrillator, or CC resumption time, nor any significant relationship when stratified by shock outcome (asystole versus OR; Table 3). There was no statistically significant difference between shock outcome types in the time to VF recurrence \( (P=0.32) \) or time to CC resumption \( (P=0.50) \).

A Kaplan–Meier analysis curve for VF recurrence within 30 seconds postshock is shown in Figure 4. There were no statistically significant differences in survival curves among the CC groups. Hazard ratios (HRs) for VF recurrence within 30 seconds for later CC groups (CC2, CC3, and CC4) relative to early CC resumption (CC1) were as follows: HR(CC2)=1.05 \( (P=0.9) \), HR(CC3)=1.75 \( (P=0.1) \), and HR(CC4)=0.67 \( (P=0.4) \).

In addition, the proportion of subjects with any VF recurrence within 30 seconds was not significantly different among patients who did or did not survive to hospital admission (33% versus 50%; \( P=0.10 \)) or discharge (38% versus 41%; \( P=0.82 \)). However, the proportion of subjects with any VF recurrence within 30 seconds was lower among patients who did achieve prehospital ROSC (29%) compared with patients who did not achieve prehospital ROSC (51%) with a \( P=0.04 \).

### Discussion

The principle finding of this study is that the recurrence of VF after a shock that succeeds in defibrillation is not related to the temporal sequence of resuming CCs. Of 226 shocks that defibrillated VF in a cohort of 88 patients with witnessed OHCA and initial VF, the HR for VF recurrence in the first 30 seconds was similar whether CC were resumed immediately or delayed after a shock. In addition, there was no relationship between age, sex, or time from Emergency Medical Services dispatch to connection of the monitor/defibrillator to the timing of VF recurrence.

It has been previously demonstrated that VF commonly recurs after a successful defibrillatory shock.\(^7\)–\(^11\) This investigation similarly finds that VF recurrence is a common event, occurring in our investigation after about three quarters of successful defibrillatory shocks and with early VF recurrence within 30 seconds in about one third of shocks. We also found that the postshock pause before resumption of CC after a successful defibrillatory shock was highly variable, with a median time of 8 seconds (interquartile range, 5–18 seconds) and exceeding 30 seconds in about one quarter of successful shocks wherein VF recurred within 30 seconds (Table 2).

VF recurrence during resuscitation is likely attributable to multiple factors that are not well understood. Higher VF recurrence rates have been observed in the setting of myocardial ischemia and during reperfusion in a rabbit model\(^17,18\) and in swine models.\(^19,20\) In addition, it has been proposed that CCs can trigger VF recurrence by a commotio-cordis–type mechanism\(^21\) or by electric depolarization from the CC itself resulting in a long-short electric activation sequence, as observed in a swine model.\(^22\)

To explore the influence of the timing of CC resumption on VF recurrence, we focused on the first 30 seconds postshock, a time frame where the postshock pause to CC resumption would be most variable.\(^23,24\) We found that the risk of early VF recurrence was not affected by when CCs were resumed. Figure 3 illustrates the lack of correlation between CC resumption and VF recurrence in this patient cohort, and there was no significant relationship by regression analysis. Furthermore, we found that VF recurred in the first 30 seconds in 11 of 51 shocks (22%) wherein CCs had not resumed until after 30 seconds postshock.

A cohort of 136 patients randomized to receive either delayed or immediate postshock CCs (according to the CPR

### Table 3. Predictors for Time to VF Recurrence

<table>
<thead>
<tr>
<th></th>
<th>All Shocks With Subsequent VF Recurrence (n=166)</th>
<th>Shocks That Result in Asystole and With Subsequent VF Recurrence (n=78)</th>
<th>Shocks That Result in Organized Rhythm (Not Ventricular tachycardia) and With Subsequent VF Recurrence (n=84)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P ) Value</td>
<td>( P ) Value</td>
<td>( P ) Value</td>
<td>( P ) Value</td>
</tr>
<tr>
<td>Age</td>
<td>0.200</td>
<td>0.099</td>
<td>0.934</td>
</tr>
<tr>
<td>Sex</td>
<td>0.089</td>
<td>0.052</td>
<td>0.374</td>
</tr>
<tr>
<td>Time from dispatch to monitor/defibrillator connection</td>
<td>0.135</td>
<td>0.445</td>
<td>0.219</td>
</tr>
<tr>
<td>CC resumption</td>
<td>0.175</td>
<td>0.487</td>
<td>0.508</td>
</tr>
</tbody>
</table>

CC indicates chest compression; and VF, ventricular fibrillation.
guidelines published in 2000 or 2005\textsuperscript{1,2} was analyzed by Berdowski et al.\textsuperscript{12} They examined the risk for VF recurrence after the first shock and found a high HR for VF to recur within the first 2 seconds of resuming CCs, regardless of CPR protocol (2000\textsuperscript{3} or 2005\textsuperscript{4} guidelines). Since the 2005 guidelines\textsuperscript{5} advocate an immediate resumption of CCs, this led to an earlier recurrence of VF in their study. Our investigation did not find a relationship between CC resumption and VF recurrence, but has important differences in methodology. Our analysis was restricted solely to witnessed arrest, whereas $\approx 40\%$ of cases analyzed by Berdowski et al\textsuperscript{12} were unwatched. We examined VF recurrences throughout the recorded resuscitation using a statistical correction for multiple shocks within the same subject, rather than the first shock alone. It is unknown whether the risk of VF recurrence in relationship to CCs may change over time within a specific subject, but there was no apparent difference in the scatter of VF recurrence and CC resumption (Figure 3B) between first and subsequent shocks in this investigation. It is also possible that CC quality may impact on VF recurrence. Although CC depth was not reported in the investigation by Berdowski et al\textsuperscript{12}, we found that CCs delivered in the Arizona SHARE registry were of high quality, with a median compression depth of 2.0 in (5.1 cm), exceeding what has been reported in the Resuscitation Outcomes Consortium Epistry-Cardiac Arrest database.\textsuperscript{23}

We also analyzed VF recurrence and CC resumption according to postshock rhythm (Figure 3C). We found no statistically significant difference in the time to VF recurrence for shocks that resulted in asystole or shocks that resulted in an OR. There was similarly no statistically significant difference in the time to CC resumption for postshock rhythms of asystole versus an OR. In addition, we found no relationship by regression analysis between VF recurrence and CC resumption according to shock outcome. Our findings differ from what was reported in a previous investigation of VF recurrence in a cohort of 32 patients.\textsuperscript{11} In that study, VF occurred more commonly during CC when the postshock rhythm was asystole and otherwise was more likely to recur in the absence of CC when the postshock rhythm was organized. A limitation of that investigation was that the duration of CCs before VF recurrence was not reported, nor was the timing of either CC resumption or VF recurrence relative to the shock. It is well known that in addition to maintaining a high fraction of time with CCs, there should also be an adequate depth, rate, and chest wall recoil,\textsuperscript{25,26} although the adoption of means to monitor CPR performance and implement quality improvement is lacking.\textsuperscript{27} The 2010 American Heart Association Guidelines\textsuperscript{28} further dictate that CC be resumed immediately postshock without performing a rhythm check. However, there remains uncertainty as to how long the postshock pause should be or can be without becoming detrimental. In a study of 815 patients in the Resuscitation Outcomes Consortium Epistry-Cardiac Arrest database, survival was lower if the preshock pause exceeded 20 seconds or the perishock (pre- and postshock) pause exceeded 40 seconds.\textsuperscript{23} However, in that study, survival was not affected by the duration of the postshock pause. Thus, the optimal postshock delay to resuming CCs is unclear, but our investigation suggests that neither a brief nor prolonged postshock pause affects the likelihood of VF recurrence.

**Limitations**

This is a retrospective analysis of cardiac arrest survivors from 2 sites in Arizona, as part of the larger SHARE database, and future work will analyze data from other sites. Furthermore, timing of drug administration with respect to shocks and CC resumption was not analyzed. It is unknown whether drugs such as amiodarone or epinephrine may change the likelihood of VF recurrence in relationship to CCs. We observed a trend for a lower proportion of any VF recurrence within 30 seconds among patients who survived to hospital admission or discharge; however, our sample size was not powered to detect a difference. The quality of the CPR filtered recordings was excellent, yet the visual identification of recurrence was determined by a single observer. In another similar study,\textsuperscript{12} it was shown there was a 96% agreement between 2 observers in determining the onset of VF using a filtered signal. Therefore, we feel it is unlikely that the lack of a second observer in this investigation to determine VF recurrence would have significantly affected our results.

**Conclusions**

In witnessed OHCA with an initial rhythm of VF, VF recurred after successful defibrillation in about three quarters of shocks. The risk of VF recurrence within 30 seconds after defibrillation was not affected by when CCs were resumed.

**Sources of Funding**

This work was supported through the Flinn Foundation and American Heart Association Endowed Chair in Electrophysiology at the Sarver Heart Center, University of Arizona College of Medicine, Tucson, AZ.

**Disclosures**

Dr Silver is employed by ZOLL Medical Corporation. Drs Bobrow and Spalte have an implementation grant that is from Medtronic Foundation to the University of Arizona and deemed by the Institutional Review Board as not human subjects research. The other authors report no conflicts.

**References**

After a defibrillatory shock for ventricular fibrillation (VF), recurrence of VF is common, requiring repeat shocks. It is unclear what factors may increase the risk for VF recurrence, but a prior investigation has related early VF recurrence to the presence of partial occlusion of left anterior descending coronary artery. Conover et al Circ Arrhythm Electrophysiol. 2010;63:17–24.

Clinical Perspective

A defibrillatory shock for ventricular fibrillation (VF), recurrence of VF is common, requiring repeat shocks. It is unclear what factors may increase the risk for VF recurrence, but a prior investigation has related early VF recurrence to the early resumption of chest compressions, raising the concern that early chest compression resumption may be detrimental. We sought to investigate factors (age, sex, time from dispatch to monitor/defibrillator application, and the timing of chest compression resumption) that would predict the risk for VF recurrence in a cohort of witnessed cardiac arrest survivors in Arizona with an initial rhythm of VF. We found that VF recurrence within 30 seconds of a shock was not related to when chest compressions were resumed in this cohort. Furthermore, there was no relationship between VF recurrence and chest compression resumption when stratified by the postshock rhythm of asystole versus organized rhythm. The impact of this investigation is that it finds that the early resumption of chest compressions does not trigger early VF recurrence and therefore supports the recommendations of the 2010 Heart Association Guidelines that emphasize early resumption of chest compressions after a shock.
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Circ Arrhythm Electrophysiol. 2014;7:633-639; originally published online July 11, 2014; doi: 10.1161/CIRCEP.114.001506
Circulation: Arrhythmia and Electrophysiology is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 1941-3149. Online ISSN: 1941-3084

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