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.1–3 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%.5 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 Board approved the study.

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 constitutes 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).

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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.

**Table 1. Patient and Resuscitation Characteristics**

<table>
<thead>
<tr>
<th>Characteristic</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>
<tr>
<td>Shock outcome</td>
<td></td>
</tr>
<tr>
<td>Ventricular fibrillation</td>
<td>59</td>
</tr>
<tr>
<td>Ventricular tachycardia</td>
<td>4</td>
</tr>
<tr>
<td>Asystole</td>
<td>102</td>
</tr>
<tr>
<td>Organized rhythm (not ventricular tachycardia)</td>
<td>120</td>
</tr>
<tr>
<td>CC resumption, s*</td>
<td></td>
</tr>
<tr>
<td>All shocks</td>
<td>8 (5–14)</td>
</tr>
<tr>
<td>For shocks that defibrillate VF</td>
<td>8 (5–18)</td>
</tr>
<tr>
<td>Ventricular fibrillation recurrence post shock, s*</td>
<td>39 (16–120)</td>
</tr>
</tbody>
</table>

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

*Median (25th–75th percentile).

**Figure 2. Subjects in the Saving Hearts in Arizona Registry and Education (SHARE) registry from 2 sites in Arizona with cardiac arrest attributable to an initial rhythm of ventricular fibrillation (VF). Patients were excluded if VF was unwitnessed, and 2 subjects were excluded because of waveform artifact or uncertain postshock rhythm, resulting in a total of 88 subjects analyzed (A). A total of 285 shocks were analyzed, of which 226 shocks successfully defibrillated VF to asystole (102 shocks), organized rhythm (120 shocks), or monomorphic VT (4 shocks; B).**

**Continuous 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
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 cor-
relations 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 sec-
onds postshock, according to CC group; correlations within the same
subject for multiple shocks were accounted for using the cluster op-
tion 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. Reaerest 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 sec-
onds. 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 subse-
quently 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

| 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 defibrillatory shocks | 59 | 60 | 56 | 51 | 226 |
| VF recurrence by 30 s, n (%) | 17 (29) | 17 (28) | 25 (45) | 11 (22) | 70 (31) |

CC indicates chest compression; and VF, ventricular fibrillation.

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

Figure 3. Scatter plot of time to ventricular fibrillation (VF) recur-
rence and time to resumption of chest compressions (CCs) after
shocks (A). The first 60 seconds after a shock is shown in B
distinguishing first shocks from second and later shocks and in
C distinguishing shocks that resulted in organized rhythm from
those that resulted in asystole.
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 achieved prehospital ROSC (29%) compared with patients who did not achieve prehospital ROSC (51%) with a P=0.04.

**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></td>
<td>PValue</td>
<td>PValue</td>
<td>PValue</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.

**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. 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 and in swine models. In addition, it has been proposed that CCs can trigger VF recurrence by a commotio-cordis–type mechanism or by electric depolarization from the CC itself resulting in a long-short electric activation sequence, as observed in a swine model.

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. 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...
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 \textasciitilde40\% of cases analyzed by Berdowski et al\textsuperscript{12} were unwitnessed. 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 recurred 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 optimum 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 Spaite 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**

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CLINICAL PERSPECTIVE

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The current evidence suggests that the early resumption of chest compressions does not trigger early VF recurrence and therefore supports the recommendations of the 2010 American Heart Association Guidelines that emphasize early resumption of chest compressions after a shock.
Resumption of Chest Compressions After Successful Defibrillation and Risk for Recurrence of Ventricular Fibrillation in Out-of-Hospital Cardiac Arrest
Zacherie Conover, Karl B. Kern, Annemarie E. Silver, Bentley J. Bobrow, Daniel W. Spaite and Julia H. Indik

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