

# Effects of Interrupting Precordial Compressions on the Calculated Probability of Defibrillation Success During Out-of-Hospital Cardiac Arrest

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**Background**—Cardiopulmonary resuscitation (CPR) creates artifacts on the ECG and, with automated defibrillators, a pause in CPR is mandatory during rhythm analysis. The rate of return of spontaneous circulation (ROSC) is reduced with increased duration of this hands-off interval in rats. We analyzed whether similar hands-off intervals in humans with ventricular fibrillation causes changes in the ECG predicting a lower probability of ROSC.

**Methods and Results**—The probability of ROSC after a shock was continually determined from ECG signal characteristics for up to 20 seconds of 634 such hands-off intervals in patients with ventricular fibrillation. In hands-off intervals with an initially high (40% to 100%) or median (25% to 40%) probability for ROSC, the probability was gradually reduced with time to a median of 8% to 11% after 20 seconds ( $P < 0.001$ ). In episodes with a low initial probability (0% to 25%; median, 5%), there was no further reduction with time.

**Conclusions**—The interval between discontinuation of chest compressions and delivery of a shock should be kept as short as possible. (*Circulation*. 2002;105:2270-2273.)

**Key Words:** cardiopulmonary resuscitation ■ defibrillation ■ electrocardiography ■ heart arrest ■ Fourier analysis

Early defibrillation provides the single best option for restoring spontaneous circulation (ROSC) in patients with ventricular fibrillation (VF).<sup>1</sup> With automated external defibrillators, a “hands-off” interval without chest compressions must occur during the period of rhythm analysis and capacitor charging before the delivery of an electric shock.<sup>1</sup> Sato et al<sup>2</sup> reported a reduced rate of ROSC with increased duration of this interval without myocardial perfusion in rats, and they concluded that minimal hands-off delays should improve the effectiveness of automated defibrillators.

We wanted to evaluate whether the probability for ROSC is reduced during a hands-off interval in patients. This cannot be studied by giving multiple shocks during the interval and recording the ROSC rate, because by definition this is a no-shock interval. A predictor for ROSC must therefore be used, and some ECG signal characteristics during VF correlate with defibrillation success rate.<sup>3-7</sup> We developed a factor indicating the percent chance of ROSC after the shock,  $P_{\text{ROSC}}(\mathbf{v})$ , that is based on VF signal characteristics from 868 defibrillation attempts in 156 patients.<sup>8,9</sup> In the present study, we studied possible changes in the ECG during hands-off intervals in patients with out-of-hospital cardiac arrest.

## Methods

In an observational, prospective study from Oslo, Norway,<sup>10</sup> we used data registered in the Heartstart 3000 defibrillator (Laerdal Medical) together with regular Utstein registration of prehospital cardiac arrest data.<sup>11</sup> We evaluated the rhythm before and after the delivery of each defibrillation shock. Details have been described elsewhere.<sup>10</sup> The Regional Committee for Research Ethics and the Norwegian Data Inspectorate approved the study.

The hands-off intervals (Figure 1) preceding 868 shocks (of which 87 caused ROSC and 781 failed to cause ROSC) in 156 patients were determined from the cardiopulmonary resuscitation (CPR) artifacts on the ECG.<sup>10</sup> The duration of the individual hands-off intervals varied (median, 20 seconds).<sup>10</sup>

## Derivation of the $P_{\text{ROSC}}(\mathbf{v})$

$P_{\text{ROSC}}(\mathbf{v})$  was developed in our previous studies<sup>8,9</sup> and is based on the centroid frequency, peak power frequency, spectral flatness, and energy features of the ECG signal using Fourier transform during the last 4 seconds of VF before 868 defibrillation attempts combined with the knowledge of whether ROSC was achieved or not. Earlier work had reported these features were related to the level of resuscitability in animals and humans.<sup>3-8</sup>

The prediction analysis was performed in 2 stages that apply pattern recognition methods. First, the ECG was spectrally characterized (feature extraction). This step included the development of an alternative, decorrelated feature set generated by principal component analysis transformation. Second, decision regions for ROSC/No-ROSC were determined and evaluated. The optimal combination

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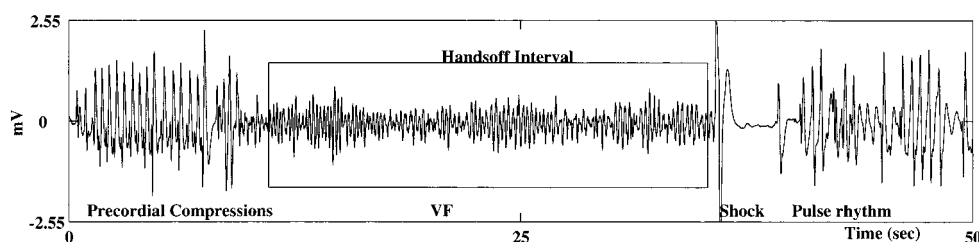
At the time of the study, Dr Eftestøl was a part-time employee of Laerdal Medical. Dr Steen serves as a consultant to and is a previous board member of Laerdal Medical.

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**Figure 1.** A 50-second ECG tracing illustrating VF with artifacts from precordial chest compressions, followed by a hands-off interval, a countershock, and return of spontaneous circulation (ROSC).

of ECG-characterizing features discriminating between ROSC and No-ROSC were selected by testing all possible feature combinations. The discriminative power was determined using a multidimensional histogram technique that estimated the a posteriori probability function for each feature combination. Further, a risk-minimizing procedure was applied to ensure that the desired sensitivity was achieved in recognizing the preshock ECG feature combination in the incidents with ROSC. To increase the reliability of the results, all data were split in training and testing sets. Thus, an ECG feature set indicating ROSC was first determined from one set of data and then tested on another set of data. From the set of ECG features ( $\mathbf{v}$ ) that best discriminated between ROSC and No-ROSC,<sup>8</sup> a single function for indicating the factor of ROSC,  $P_{ROSC}(\mathbf{v})$ , was then developed using a Bayesian decision support model.<sup>8,9</sup>

**Hands-Off Intervals**

Each interval was split into 4-second blocks with a 3.75-second overlap. From each block,  $P_{ROSC}(\mathbf{v})$  was computed on a 500-MHz computer. For a 10-second hands-off-interval, the computer used 1 second to read the consecutive ECG blocks and to compute the signal characteristics and  $P_{ROSC}(\mathbf{v})$  values. This should be within the requirements for a real-time monitoring device connected to a defibrillator.

Intervals were excluded if the ECG was noisy (muscle artifacts, electrode noise, change of defibrillator components), if the start of the hands-off interval preceded the start of the recording, or if  $P_{ROSC}(\mathbf{v})$  was not defined at zero time due to the restricted function domain.<sup>9</sup> Thus 141, 66, and 27 intervals, respectively, were removed, leaving 634 intervals for analysis (73% of the total material). Before analysis, we hypothesized that intervals starting with very low  $P_{ROSC}(\mathbf{v})$  could not deteriorate much further. To avoid the possibility of these intervals overshadowing intervals with higher initial  $P_{ROSC}(\mathbf{v})$ , which we hypothesized would have a larger potential for ECG deterioration, intervals were subdivided according to the initial value of  $P_{ROSC}(\mathbf{v})$  at the start of the hands-off intervals. Low, medium, or high probabilities for ROSC were defined as  $P_{ROSC}(\mathbf{v})$  of 0.00 to 0.25, 0.25 to 0.40, and 0.40 to 1.00, respectively (Table).

Because  $P_{ROSC}(\mathbf{v})$  was updated every 0.25 seconds, we computed a time series reflecting the changes in probability for ROSC for every interval. The median value and 25th and 75th percentiles were

calculated for each time instant, thus representing the average  $P_{ROSC}(\mathbf{v})$  and its uncertainty.

**Statistical Analysis**

Data are presented as median values (25th and 75th percentiles). For each  $P_{ROSC}(\mathbf{v})$  time series subdivision, the  $P_{ROSC}(\mathbf{v})$  measurements at  $t=0$  were compared with the measurements at  $t=5, 10, 15,$  and  $20$  seconds using the Kruskal-Wallis nonparametric one-way ANOVA and Scheffe’s multiple comparison test. Statistical significance was set at  $P<0.05$ .

**Results**

The hands-off intervals with a high initial  $P_{ROSC}(\mathbf{v})$  deteriorated rapidly within the first few seconds to the medium level, followed by a slower rate of deterioration into the low level (Table and Figure 2). The medium initial level  $P_{ROSC}(\mathbf{v})$  subgroup showed a slower deterioration toward the low level and, after 5 seconds, the 2 groups deteriorated in parallel (Table and Figure 2). There was no significant change in  $P_{ROSC}(\mathbf{v})$  with time in the low level subgroup (Table and Figure 2).

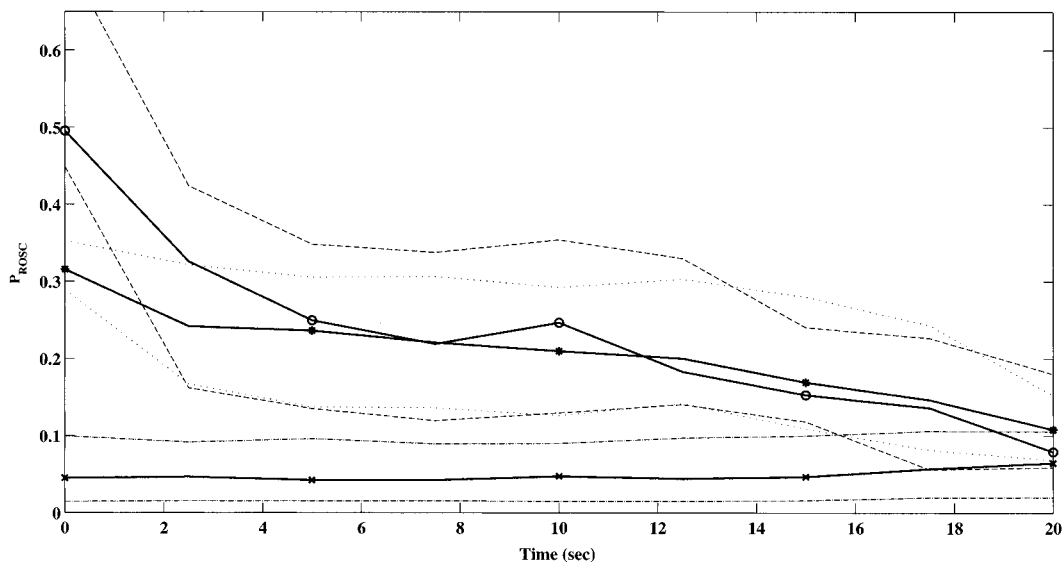
**Discussion**

The present prospective ECG study indicates that the chance for successful defibrillation with ROSC decreases during periods without chest compressions in patients starting with a high-to-median chance of success. The probability of success decision support model was determined from VF signal characteristics previously found to discriminate well between ROSC and No-ROSC episodes.<sup>8,9</sup> The results are consistent with an outcome study in rats,<sup>2</sup> in which the ROSC rate and 24- and 48-hour survival were gradually reduced with an increased interval from 10 to 40 seconds between discontinuation of chest compressions and shock delivery.

**Median (25th–75th Percentile) Probability for Successful Defibrillation With Return of Spontaneous Circulation,  $P_{ROSC}(\mathbf{v})$ , at the Start ( $t=0$ ) and After 5, 10, 15, and 20 Seconds of Hands-Off Intervals, Grouped According to Initial  $P_{ROSC}(\mathbf{v})$  of 0.00–0.25, 0.25–0.40, and 0.40–1.00**

Group	Time, s									
	0		5		10		15		20	
n	$P_{ROSC}(\mathbf{v})$	n	$P_{ROSC}(\mathbf{v})$	n	$P_{ROSC}(\mathbf{v})$	n	$P_{ROSC}(\mathbf{v})$	n	$P_{ROSC}(\mathbf{v})$	
0.00–0.25	543	0.05 (0.02–0.10)	543	0.04 (0.02–0.10)	509	0.05 (0.02–0.09)	303	0.05 (0.02–0.10)	139	0.07 (0.02–0.11)
0.25–0.40	60	0.32 (0.29–0.35)	59	0.24 (0.14–0.31)‡	56	0.21 (0.13–0.29)†	40	0.17 (0.11–0.28)*	15	0.11 (0.07–0.15)*
0.40–1.00	31	0.50 (0.45–0.72)	31	0.25 (0.14–0.35)§	30	0.25 (0.13–0.35)§	26	0.15 (0.12–0.24)†	16	0.08 (0.06–0.18)†

\* $P<0.0000001$ ; † $P<0.000001$ ; ‡ $P<0.00001$ ; § $P<0.001$  vs time 0 s within group.



**Figure 2.** The change in probability for successful defibrillation with return of spontaneous circulation (ROSC),  $P_{ROSC}(v)$ , with time during the median 20-second interval without CPR after initiation of ECG analysis before a defibrillation attempt. The data are divided into 3 groups with an initial high (40% to 100%;  $\circ$ ), medium (25% to 40%;  $*$ ), and low (0 to 25%;  $\times$ )  $P_{ROSC}(v)$  and are presented as the medians with the 25th and 75th percentiles.

Only 8 of the 31 (26%) hands-off intervals in the group with an initial high level of  $P_{ROSC}(v)$  (median, 50%) were defibrillated with ROSC at the end of the intervals. Assuming an accurate estimate of the initially high level for these intervals, one might speculate a doubled success rate in this group if defibrillated immediately. For the median level group, 14 of 61 patients (22%) had successful outcomes versus an initial median  $P_{ROSC}(v)$  prediction of 32% success. In this group, one might speculate that five or six unsuccessful defibrillation attempts could have been successful if defibrillated immediately.

It is not surprising that the probability of ROSC did not deteriorate further in the hands-off episodes that already had a low (median, 5%) chance of success at the onset. In this group, 520 of 536 shocks were unsuccessful. We would not expect the success rate to be worse if defibrillations had occurred at the beginning of the intervals for this group.

As pointed out earlier, hands-off intervals are required to allow for ECG analysis and capacitor charging when using automated external defibrillators.<sup>1</sup> During rhythm analysis, this is required to avoid contaminating the ECG by CPR artifacts. Recent studies have demonstrated the possibility of removing these CPR artifacts from human VF, indicating the possibility of performing ECG analysis during CPR.<sup>12,13</sup> This could reduce the hands-off intervals, increasing the expected rate of successful defibrillations.

There are limitations in this study. First, we only reported changes in the ECG indicating changes in the probability of ROSC, not actual rates of ROSC, because that is impossible. As soon as ROSC is attempted by defibrillation, the hands-off interval is, by definition, terminated. Second, the data used to derive  $P_{ROSC}(v)$  are limited, especially the number of ROSC observations; thus, there is some uncertainty in  $P_{ROSC}(v)$ ,<sup>8,9</sup> but not enough to make the reduction with time for  $P_{ROSC}(v)$  invalid. Third, this study was performed on the same patient

material used to determine the probability factor  $P_{ROSC}(v)$ .<sup>9</sup> As explained earlier, the previous determination of  $P_{ROSC}(v)$ <sup>9</sup> was done from only the last 4 seconds of ECG during the hands-off intervals, whereas in the present study, we looked at changes in  $P_{ROSC}(v)$  with time during the entire hands-off interval. We re-ran the experiments after removing the data involved in deriving  $P_{ROSC}(v)$ . This gave fewer measurements at 5, 10, 15, and 20 seconds and thus resulted in weaker, but still significant, probability values with the same conclusions. Thus, the conclusion of our probability analysis is still valid when excluding the material from which  $P_{ROSC}(v)$  was derived. Fourth, 27% of the intervals were excluded from the study before the analysis. One might speculate whether this might have biased our results. All intervals were excluded from pre-analysis set criteria. We studied how each of these intervals distributed into the low, medium, and high level groups and found that there was little possibility of this exclusion biasing our results. Finally, the thresholds for  $P_{ROSC}(v)$  between the groups were set in an ad hoc manner, although this was done before performing the analysis. As previously explained, this division was done because we assumed that most hands-off intervals would start with a very low probability of ROSC that could not deteriorate much further. If all data were studied as one group, these intervals could overshadow those with a high initial probability of success, causing a type II statistical error.

We conclude that during resuscitation from VF, the intervals between discontinuation of chest compressions and delivery of a shock should be kept as short as possible.

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