Although cardiac electrical activity in ventricular fibrillation (VF) is apparently highly disordered, Damle et al. 1 and Bayly et al. 2 found strong evidence for local spatial organization, paving the way for extensive further investigation. Grillner et al. 3 characterized VF as spatio-temporal chaos, finding underlying dynamic order. Gray, Pertsov and Jalife 4 and Witkowski et al. 5 demonstrated the existence of multiple spirals in VF. More recently, Bayly et al. 6 quantified spatial correlation in VF by demonstrating a correlation length of 4-40 mm. If a degree of organization and periodicity exists during VF, perhaps the current required to defibrillate could be reduced if the shock were delivered at an optimum point in the fibrillatory cycle. Perhaps if the shock were delivered during a time interval when a large portion of the myocardium is depolarized or refractory, then less current would be required to depolarize an additional portion of the myocardium to reach a critical mass for defibrillation. Finally, defibrillation at such a time in the cardiac cycle might minimize the chances that VF would reinitiate following defibrillation (cf. refs 7, 8).

### Purpose and Hypothesis

**Purpose:** reduce defibrillation threshold for practical, implantable defibrillators

**Hypothesis:** defibrillation threshold can be reduced by timing with respect to spatio-temporal data

**Limitations imposed in clinical practice:**
- Small number of allowed sensing electrodes
- Limited computational power
- Structure of waveforms - see below
- Baseline variability and drift
- Amplitude variability

### Study Goals

To determine whether success of defibrillation can be improved by suitably timing defibrillation shocks. Current internal defibrillators synchronize the shock to an activation event and 4 cm distal both recording/defibrillation catheters. Evaluating the criterion required to defibrillate could be reduced if the shock were delivered at an optimum point in the fibrillatory cycle. Perhaps if the shock were delivered during a time interval when a large portion of the myocardium is depolarized or refractory, then less current would be required to depolarize an additional portion of the myocardium to reach a critical mass for defibrillation. Finally, defibrillation at such a time in the cardiac cycle might minimize the chances that VF would reinitiate following defibrillation (cf. refs 7, 8).

### Methods

In a prospective study directed by Teri Whitman of Medtronic, four isoflurane-anesthetized mongrels were instrumented with a Medtronic 6944 true bipolar lead in the RV apex, a diagnostic catheter in the great cardiac vein, and a subcutaneous patch EGM. In addition, a 2.8-2 mm diagnostic catheter was placed along the RV free wall for the retrospective study described herein. Fibrillation was induced with a T shock and defibrillation was attempted after 10 seconds of VF using one of four synchronization methods: 1) asynchronous, or synchronized to the first sensed activation from 2) RV tip/ring electrogram (EGM), 3) RV coil subcutaneous patch EGM, or 4) LV bipolar EGM. Twenty sets of 4 shocks were given at energies stepping around the overall success: 1.66±0.08; failure 1.38±0.08 (mean ± SEM), p=0.016, paired t-test). Moreover, defibrillation was significantly more successful when the both the apex and most distant site were in the repolarizing state (65% vs. 51%, chi-squared = 4.88, p < 0.05). This criterion was met 26% of the time. Finally, in a preliminary estimate with logistic regression, applying this criterion appears to reduce defibrillation energy by 19+12-9%.

### Results

The number of sites in the repolarizing state that correlated with defibrillation success (success: 1.66±0.08; failure 1.38±0.08 (mean ± SEM), p=0.016, paired t-test). Moreover, defibrillation was significantly more successful when the both the apex and most distant site were in the repolarizing state (65% vs. 51%, chi-squared = 4.88, p < 0.05). This criterion was met 26% of the time. Finally, in a preliminary estimate with logistic regression, applying this criterion appears to reduce defibrillation energy by 19+12-9%.

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### TYPICAL WAVEFORMS (unipolar electrograms)

- Waveforms: Unipolar electrograms from selected locations in the RV
- Voltage (mV)
- Time (ms)
- Apex
- 1 cm
- 3 cm
- 4 cm

### Selecting a criterion

**Look at successes and failures**

Study behavior of electrograms

**Unipolar electrograms at the apex and 4 cm distal**

<table>
<thead>
<tr>
<th>Average number of sites in repolarization</th>
<th>Apex</th>
<th>1 cm</th>
<th>3 cm</th>
<th>4 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Success</td>
<td>16</td>
<td>12</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Failure</td>
<td>20</td>
<td>16</td>
<td>12</td>
<td>8</td>
</tr>
</tbody>
</table>

Chi-squared = 4.84, p < 0.05

### Evaluating the criterion

- **Consider** how often criterion met and effect upon defibrillation success

**Criterion:** Apex and 4 cm distal body polarizing

**How often met?** 26% of time

**Chi-squared** = 4.84, **p < 0.05**

### BIBLIOGRAPHY

2. Gray, Pertsov and Jalife 4 and Witkowski et al. 5 demonstrated the existence of multiple spirals in VF. More recently, Bayly et al. 6 quantified spatial correlation in VF by demonstrating a correlation length of 4-40 mm.
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