Ventricular Tachycardia Rate and Morphology Determine Energy and Current Requirements for Transthoracic Cardioversion

Richard E. Kerber, MD; Michael G. Kienzle, MD; Brian Olshansky, MD; Albert L. Waldo, MD; David Wilber, MD; Mark D. Carlson, MD; Ann M. Aschoff, RN; Sally Birger, RN; Laurie Fugatt, RN; Susan Walsh, RN; Martin Rockwell, MSEE; and Francis Charbonnier, PhD

Background. The electrical current and energy required to terminate ventricular tachyarrhythmias are known to vary by arrhythmia: Ventricular tachycardia (VT) is generally considered to require less energy than ventricular fibrillation (VF). The hypothesis of our study was that current requirements for transthoracic termination of VT are further determined by VT rate and QRS complex morphology.

Methods and Results. We prospectively studied 203 patients who received a total of 569 shocks for VT or VF by following a current-based protocol. This protocol recommended shocks for VT beginning at 18 A (70±22 J) and shocks for VF beginning at 25 or 30 A (137±52 J or 221±70 J). The ventricular tachyarrhythmias were subclassified as monomorphic VT (MVT): uniform QRS complex morphology on surface electrocardiogram and heart rate >100 beats per minute; polymorphic VT (PVT): nonuniform QRS complex morphology and heart rate ≤300 beats per minute; or VF: nonuniform QRS complex morphology and heart rate >300 beats per minute. We found that shocks of 18 A and 25 A for terminating MVT had success rates of 69% and 82%, respectively, whereas such low-current shocks were less successful for PVT (33% at 18 A) and for VF (19% at 18 A, 53% at 25 A). High-current shocks of 35 A and 40 A were equally successful for the three ventricular tachyarrhythmias. Subdividing MVT revealed that slower MVT (heart rate <200 beats per minute) had a significantly better success rate with low-current shocks of 18 A and 25 A than did faster MVT (>200 beats per minute) (89% versus 72% success, p<0.01). Bundle branch block morphology, QRS axis, and duration of ventricular tachyarrhythmia did not alter current requirements.

Conclusions. Heart rate and electrocardiographic degree of organization of ventricular tachycardia are important determinants of transthoracic energy and current requirements for cardioversion and defibrillation. Transthoracic termination of MVT requires relatively low current or energy, but PVT behaves more like VF and requires higher electrical current or energy. (Circulation 1992;85:158–163)

Energy and current requirements for transthoracic defibrillation and cardioversion are arrhythmia specific. Most authorities recommend initial shock energies of 50–100 J for cardioversion of ventricular tachycardia (VT).¹ Ventricular tachycardias may be subclassified by rate and QRS complex morphology,² and internal defibrillation energy requirements are altered by these variables; polymorphic VT (PVT) and ventricular fibrillation (VF) require higher internal defibrillation energy and current than monomorphic VT (MVT).³ However, there are no data presently available on the effect of QRS complex morphology or rate on energy and current requirements for transthoracic cardioversion of VT. We hypothesized that VT rate, QRS complex morphology, and related characteristics would determine the electrical current and energy requirements for transthoracic cardioversion, and, specifically, that the more electrically disorganized

From the University of Iowa, Iowa City; Case Western Reserve University, Cleveland, Ohio; Loyola University, Maywood, Ill.; and the Hewlett-Packard Corporation, McMinnville, Ore.

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Address for reprints: Richard E. Kerber, MD, Department of Medicine, 4215 RCP, University of Iowa Hospital, Iowa City, IA 52242.

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rhythm of PVT would require higher electrical current and energy than MVT.

Methods

This study was approved by the University of Iowa Human Research Committees of the University of Iowa, University Hospitals of Cleveland (Case Western Reserve University), and Loyola University. We prospectively collected data from 203 patients who were part of an ongoing study of current-based defibrillation. These patients received 569 direct current shocks for VT or VF. One hundred seventy-two patients received these shocks for arrhythmias induced in the electrophysiology laboratory. The remaining 31 patients were treated for spontaneous ventricular tachyarrhythmias occurring in the coronary care unit or other in-patient areas. The patients were receiving a variety of antiarrhythmic and other cardiac drugs. No attempt was made to control this or to include data from patients receiving only certain drugs.

In the electrophysiology laboratory, we used self-adhesive monitor-defibrillator electrode pads (R2 pads, Darox Corp.) placed apex-anterior or anteroposterior to deliver shocks. In other areas, hand-held paddle electrodes placed apex-anterior were used.

Shocks were administered from specially modified Hewlett-Packard 43100A defibrillators, which use a damped sinusoidal waveform. When the operator initiated the charge cycle, the defibrillator predicted transthoracic impedance (ohms) by using a previously validated "test-pulse" technique.4 The predicted impedance was then used to charge the capacitor to the exact energy (joules) necessary to deliver the operator-specified current (amperes [A]) against the impedance that the defibrillator had just determined. In each center, the operator had a choice of three current settings: 18, 25, or 35 A (Case Western Reserve and Loyola) or 18, 30, or 40 A (Iowa). These current settings were chosen on the basis of our previous experience with current-based defibrillation and cardioversion.5 The settings were varied between the centers to allow (when the data from the three centers were combined) closely spaced current increments, facilitating current versus success comparisons. The actual transthoracic impedance, delivered energy, and peak current were recorded for each shock.

The study protocol suggested the following sequences of current selection for VT: an initial shock of 18 A followed by the intermediate current setting (25 or 30 A) if the first shock failed and by the highest setting (35 or 40 A) if the second shock also failed. For VF, we recommended that the initial shock be administered at the intermediate current setting (25 or 30 A) with the second and subsequent shocks at the highest setting (35 or 40 A) if the first shock failed. This protocol was not followed in all patients. In some cases, arrhythmias initially thought to be VF and shocked with higher currents were, on review, reclassified as VT (see below). In other cases, VF was initially taken to be VT. The data presented in the results represent actual events; if a lower-current shock was omitted in any patient, no entry was made for that current in that patient.

The criteria for classification of arrhythmias were based on the analysis of the 10 cycles preceding the shock, using surface electrocardiogram (ECG) recordings (three to six leads per patient) as follows: MVT: uniform QRS complex morphology, cycle length <600 msec; heart rate >100 beats per minute; PVT: nonuniform QRS complex morphology, cycle length ≥200 msec; heart rate ≤300 beats per minute; VF: nonuniform QRS complex morphology, cycle length <200 msec; heart rate >300 beats per minute. Heart rates were determined by measuring and averaging the 10 cardiac cycles immediately preceding the shock.

A successful shock was one that terminated the ventricular tachyarrhythmia. In all except eight cases, this was immediately followed by the restoration of sinus rhythm. In three cases, atrial fibrillation followed the shock, in three other cases asystole resulted, and in two patients with implanted pacemakers, paced rhythms followed the shock.

To define further the parameters that could potentially determine shock success for ventricular tachycardias, we identified a subgroup of 112 patients who had received at least one low-current shock (18 or 25 A) for VT only (both MVT and PVT were included). In those patients who received shocks for ventricular tachyarrhythmias provoked during electrophysiological stimulation studies, the exact duration of the arrhythmia could be determined from continuous recordings and multiple surface leads allowed determination of QRS axis and bundle branch block morphology. In this subgroup, we compared the following parameters: right versus left bundle branch block morphology (QRS complex appearance in V1) and superior versus inferior frontal plane electrical axis and duration of VT (<60 seconds versus ≥60 seconds). Not all parameters could be determined in every patient.

We also compared the success rate of low-current shocks for "slow" MVT (cycle length >300 msec; rate <200 beats per minute) versus "fast" MVT (cycle length ≤300 msec; rate ≥200 beats per minute). By excluding PVT from this latter analysis, we were able to assess the influence of heart rate alone within MVT, the single most common arrhythmia.

Statistical Analysis

To compare proportion of success among the three types of arrhythmia, Fisher’s exact test was used to test for association between type of arrhythmia and outcome at each current level. When the test showed a significant association, Fisher’s exact test was then performed on subsets of 2×2 tables for pairwise comparisons of the types of arrhythmias.

The same tests were performed to compare proportion of success among the four current levels for each type of arrhythmia.


\(\chi^2\) tests were used to compare proportion of success within VT by rate, QRS complex morphology, bundle branch block morphology, QRS axis, and VT duration.

\section*{Results}

The success rates between arrhythmias of all shocks at 18, 25, 30, and 35/40 A (combined) are presented in Table 1 and Figure 1. Shocks of 18 A and 25 A succeeded in terminating MVT significantly more often than PVT (18 A) or VF (18 A and 25 A). Shocks of 30 A terminated MVT but not PVT more often than VF. There were no significant differences in the success rates of 35/40-A shocks between arrhythmias.

A few individual patients received large numbers of shocks. To avoid biasing the data by analyzing such multishock patients, we also analyzed current versus shock success to include first and second shocks only (Table 1 and Figure 2). The results are similar to the all-shocks data of Table 1 except that the MVT versus PVT success rate comparisons at 18 A and 25 A are of only borderline significance.

We also compared success rates by current level within each arrhythmia. For all shocks (Table 1), the success rates of 25-A, 30-A, and 35/40-A shocks for PVT were higher \(p<0.05\) than for 18-A shocks; for VF, 25-A, 30-A, and 35/40-A shocks were similarly higher than for 18-A shocks \(p<0.01\). There were no significant differences in the success rates of the different current shocks for MVT when analyzing all shocks. When the analysis was restricted to first and second shocks (Table 1), 25-A and 30-A success rates for MVT were higher \(p<0.05\) than for 18 A; for VF, the success rates at 25-A, 30-A, and 35/40-A were higher \(p<0.01\) than for 18 A. There were no differences between the success rates of different current levels for PVT when the analysis was restricted to first and second shocks.

\begin{table}
\centering
\caption{Current Versus Success for Ventricular Arrhythmias}
\begin{tabular}{lccc}
\hline
& \textbf{MVT} & \textbf{PVT} & \textbf{VF} \\
\textbf{Amperes} & \textbf{Success/total} & \textbf{Success/total} & \textbf{Success/total} \\
\hline
\textbf{All shocks (n=569)} & & & \\
18 & 88/128 (69\%) & 5/15 (33\%) \textsuperscript{*} & 6/32 (19\%) \textsuperscript{*} \\
25 & 51/62 (82\%) & 17/24 (71\%) \textsuperscript{†} & 19/36 (53\%) \textsuperscript{†} \\
30 & 52/64 (81\%) & 23/31 (74\%) \textsuperscript{‡} & 38/63 (60\%) \textsuperscript{‡} \\
35/40 & 21/31 (68\%) & 16/20 (80\%) \textsuperscript{‡} & 44/63 (70\%) \textsuperscript{‡} \\
\hline
\textbf{First and second shocks only (n=374)} & & & \\
18 & 54/81 (67\%) & 3/9 (33\%) \textsuperscript{¶} & 5/25 (20\%) \textsuperscript{*} \\
25 & 49/57 (86\%) \textsuperscript{†} & 13/20 (65\%) \textsuperscript{¶} & 19/35 (54\%) \textsuperscript{∗} \\
30 & 37/42 (88\%) \textsuperscript{†} & 12/16 (75\%) & 31/48 (65\%) \textsuperscript{¶} \\
35/40 & 6/8 (75\%) & 5/6 (83\%) & 20/28 (71\%) \textsuperscript{‡} \\
\hline
\multicolumn{4}{l}{MVT, monomorphic ventricular tachycardia; PVT, polymorphic ventricular tachycardia; VF, ventricular fibrillation.} \\
\multicolumn{4}{l}{Numbers in parentheses show percent of success.} \\
\multicolumn{4}{l}{\textsuperscript{*}p<0.01 vs. MVT; \textsuperscript{†}p<0.05 vs. 18 A; \textsuperscript{‡}p<0.01 vs. 18 A; \textsuperscript{¶}p<0.05 vs. MVT; \textsuperscript{∥}p=0.07 vs. MVT; \textsuperscript{*}p=0.05 vs. MVT.} \\
\end{tabular}
\end{table}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure1}
\caption{Graph shows current vs. percent of success for monomorphic ventricular tachycardia (MVT) vs. polymorphic ventricular tachycardia (PVT) vs. ventricular fibrillation (VF) for all shocks. For comparisons of success rates at different current levels within each arrhythmia, see Table 1.}
\end{figure}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure2}
\caption{Graph shows current vs. percent of success for monomorphic ventricular tachycardia (MVT) vs. polymorphic ventricular tachycardia (PVT) vs. ventricular fibrillation (VF) for first and second shocks only. For comparisons of success rates at different current levels within each arrhythmia, see Table 1.}
\end{figure}
Table 2. Success Rates of Low-Current Shocks for Monomorphic and Polymorphic Ventricular Tachycardia

<table>
<thead>
<tr>
<th>Classification</th>
<th>Total shocks</th>
<th>Successful shocks</th>
<th>% Successful</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>All shocks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cycle length ≤300 msec</td>
<td>139</td>
<td>95</td>
<td>68%</td>
<td></td>
</tr>
<tr>
<td>(heart rate ≥200/min)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cycle length &gt;300 msec</td>
<td>68</td>
<td>58</td>
<td>85%</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>(heart rate &lt;200/min)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right bundle branch block</td>
<td>42</td>
<td>33</td>
<td>79%</td>
<td></td>
</tr>
<tr>
<td>Left bundle branch block</td>
<td>47</td>
<td>34</td>
<td>72%</td>
<td>NS</td>
</tr>
<tr>
<td>Superior axis</td>
<td>62</td>
<td>48</td>
<td>77%</td>
<td>NS</td>
</tr>
<tr>
<td>Inferior axis</td>
<td>26</td>
<td>19</td>
<td>73%</td>
<td></td>
</tr>
<tr>
<td>Duration &lt;60 sec</td>
<td>96</td>
<td>66</td>
<td>69%</td>
<td></td>
</tr>
<tr>
<td>Duration ≥60 sec</td>
<td>40</td>
<td>33</td>
<td>83%</td>
<td>NS</td>
</tr>
<tr>
<td>First and second shocks only</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cycle length ≤300 msec</td>
<td>116</td>
<td>78</td>
<td>67%</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>(heart rate ≥200/min)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cycle length &gt;300 msec</td>
<td>38</td>
<td>32</td>
<td>84%</td>
<td></td>
</tr>
<tr>
<td>(heart rate &lt;200/min)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Low-current shocks, 18 and 25 A; NS, not significant.

Data from the subgroup of patients receiving low-current shocks of 18 A or 25 A for VT (PVT and MVT combined) only are presented in Table 2. There were no differences in success rates of all low-current shocks given for VT when considering the parameters of bundle branch block morphology, pattern of QRS complex morphology, QRS axis, or duration of provoked ventricular tachyarrhythmia. The low-current shocks were more successful when the VT cycle length was >300 msec (i.e., when VT rate was <200 beats per minute). Similar results were obtained when the analysis was restricted to first and second shocks only (Table 2). As shown in Table 3, for MVT only, low-current shocks again were more successful when the VT cycle length was >300 msec (i.e., when VT rate was <200 beats per minute) whether all shocks or only first and second shocks are analyzed.

Table 4 gives the energies (mean±SD) required to generate the various current levels chosen for our current-based study. For any chosen current, the energy required to generate that current is determined by transthoracic impedance,\(^5,6\) which was 75±17 Ω for first shocks.

Table 3. Success Rate of Low-Current Shocks for Monomorphic Ventricular Tachycardia

<table>
<thead>
<tr>
<th>Heart rate</th>
<th>Total shocks</th>
<th>Successful shocks</th>
<th>Successful</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>All shocks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥200/min</td>
<td>109</td>
<td>78</td>
<td>72%</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>&lt;200/min</td>
<td>62</td>
<td>55</td>
<td>89%</td>
<td></td>
</tr>
<tr>
<td>First and second shocks only</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥200/min</td>
<td>94</td>
<td>66</td>
<td>67%</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>&lt;200/min</td>
<td>33</td>
<td>29</td>
<td>84%</td>
<td></td>
</tr>
</tbody>
</table>

Low-current shocks, 18 and 25 A.

Discussion

The principal findings of this study are that 1) transthoracic cardioversion of MVT can be accomplished using low current or energy, and 2) PVT requires higher current or energy for transthoracic cardioversion. In this respect, PVT behaves similarly to VF.

Comparison With Other Studies

Standard recommendations for transthoracic shock termination of ventricular tachyarrhythmias differentiate between VF and VT, invariably recommending lower energies and currents for VT.\(^1\) However, there are no data available concerning different energy/current requirements for MVT versus PVT when transthoracic shocks are given. There are data available from internal defibrillation (electrodes directly applied to the epicardial ventricular surface). Winkle et al.,\(^3\) in patients undergoing defibrillator implants, administered truncated exponential shocks from an apical patch–superior vena caval spring electrode configuration. Episodes of induced ventricular tachyarrhythmias were classified as “ventricular
tachycardia of stable morphology (i.e., MVT), polymorphic ventricular tachycardia, or ventricular fibrillation on the basis of the surface ECG. When increasing the energy progressively from 1 to 25 J, these investigators found a virtually uniform conversion rate for MVT (77–85%) but a progressively increasing conversion rate for PVT and VF (8% increasing to 92% with increasing energy). These findings from internal defibrillation studies are remarkably similar to our transthoracic data.

**Table 4. Energy Equivalents of Selected Currents**

<table>
<thead>
<tr>
<th>Current Type</th>
<th>Amperes (selected)</th>
<th>Joules (delivered)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monomorphic ventricular tachycardia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>70±22</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>125±56</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>179±72</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>235±124</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>309±72</td>
<td></td>
</tr>
<tr>
<td>Polymorphic ventricular tachycardia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>77±50</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>128±55</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>208±76</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>256±128</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>283±112</td>
<td></td>
</tr>
<tr>
<td>Ventricular fibrillation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>83±29</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>137±52</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>221±70</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>285±76</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>336±78</td>
<td></td>
</tr>
</tbody>
</table>

Values are mean±SD.

The varying energy requirements for cardioversion of ventricular tachyarrhythmias are analogous to those of atrial tachyarrhythmias: Atrial flutter, a more organized arrhythmia than atrial fibrillation, terminates with lower electrical doses than does atrial fibrillation. Why might this be the case? The current and energy differences noted for arrhythmia termination between rapid and disorganized ventricular tachyarrhythmias (PVT and VF) and organized MVT are likely due to a number of factors. In MVT, the myocardium is generally in a more uniform state of depolarization and recovery. Nonuniformity appears to play a role in the reinitiation of VF after an unsuccessful subthreshold shock in experimental models of fibrillation-defibrillation. Sustained MVT related to an old myocardial infarction appears to arise from reentrant excitation within a discrete region in most patients. Such regions would be expected to be relatively easily depolarized by smaller amounts of transmyocardial current, as our data demonstrated. In disorganized ventricular tachyarrhythmias, PVT and VF, the wave fronts are larger, multiple, and not discretely localized, thereby involving more myocardial mass and increasing the energy requirement for successful conversion to normal sinus rhythm.

Evidence has been presented that some polymorphic ventricular tachyarrhythmias, such as torsade de points, may have a nonreentrant mechanism, for example, in cesium-based experimental models. If true, the energy requirements for nonreentrant ventricular tachyarrhythmias may differ. Finally, the energy requirements for conversion have been linked to effects of antiarrhythmic drugs on specific cardiac ionic channels (Na⁺ and K⁺) in experimental preparations. In theory, the availability of these ionic channels could be influenced by both rate and level of organization of the ventricular arrhythmia.

We could not find an effect of right versus left bundle branch block morphology or superior versus inferior axis on energy requirements for cardioversion of VT. We also could not demonstrate an effect of the duration of tachyarrhythmias, but this may be a function of the relative brevity of the induced tachyarrhythmias, as their duration rarely exceeded 2 minutes. Differences related to duration may be difficult to demonstrate over this short time frame and may be obscured by variability in hemodynamic response.

We chose criteria for arrhythmia classification based on the surface ECG because this is the clinical information that would be available immediately to operators of defibrillators.

**Conclusions**

The rapid, electrically disorganized tachyarrhythmias of PVT and VF require more electric current or energy for transthoracic cardioversion than does MVT. If a low-current-level shock is administered (18 A or 77±50 J), the success rate for termination of PVT will be poor (33%, similar to VF), whereas such low-current shocks will terminate 69% of MVT. Thus, a selected energy level of 70 J or 100 J, specified on most commercially available defibrillators, is appropriate for attempted cardioversion of MVT. Shocks of 25 A or 30 A (128±55 or 208±76 J) are more appropriate for PVT, yielding success rates of 71–74%. These current levels will be achieved in most cases by choosing energies of 150–200 J.

**Acknowledgment**

We gratefully acknowledge the statistical assistance of Bridget Zimmerman, PhD.

**References**


KEY WORDS • transthoracic cardioversion  • ventricular tachycardia  • ventricular fibrillation
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