Factors Influencing the Success of Ventricular Defibrillation in Man

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SUMMARY  To define the factors influencing the success of emergency ventricular defibrillation, we identified 52 patients defibrillated at the University of Iowa Hospital during 1974–1976. Thirty-eight patients were successfully defibrillated at least once; 14 could not be defibrillated, despite multiple attempts. Comparisons between these groups revealed no significant differences in body weight, heart weight, energy per kilogram of body weight and energy per gram of heart weight. Factors that militated against successful defibrillation included a prolonged delay before the first defibrillatory shock (successful 7 ± 7 minutes (sd); unsuccessful 17 ± 13 minutes, \( p < 0.001 \)), acidosis (successful pH 7.36 ± 0.22; unsuccessful pH 7.23 ± 0.12, \( p = 0.05 \)) and hypoxia (successful \( \text{PO}_2 \) 100 + 98 torr; unsuccessful \( \text{PO}_2 \) 40 ± 67 torr; \( p = 0.06 \)). These three conditions tended to occur together in individual patients. Metabolic factors are important in determining defibrillation success; however, the role of high-energy doses is uncertain.

RECENT REPORTS\(^1\)\(^-\)\(^2\) have suggested that body weight is a major determinant of the success of emergency ventricular defibrillation; heavy patients were more difficult to defibrillate. It has been suggested that the energy dose for defibrillation should be weight-related, and higher-output defibrillators should be made available for use on heavy patients.\(^3\)\(^,\)\(^4\) Not all investigators have agreed, however.\(^4\)\(^,\)\(^7\) The issue is important, because the application of excessive electrical energy to the heart can cause myocardial necrosis,\(^6\)\(^,\)\(^8\) and high-energy shocks should not be used for defibrillation unless necessary. Whether higher-energy defibrillators than presently available should be provided depends on clarification of the factors influencing the success of ventricular defibrillation. The purpose of this study was to identify these factors further.

Methods

All patients who undergo “Code Blue” cardiopulmonary resuscitation procedures at the University of Iowa Hospitals are reported to the Cardiopulmonary Resuscitation Committee. We reviewed the committee’s files for the years 1974–1976 to identify all patients who received DC electrical shocks for ventricular fibrillation. The charts of these patients were reviewed to determine the following: body weight, heart weight (if an autopsy was performed), arterial blood gas determinations, and the time between the onset of cardiac arrest (defined as the start of cardiopulmonary resuscitation procedures) and the administration of the first defibrillatory shock. Arterial blood gases were obtained during resuscitation and defibrillation or within 1 hour of the start of these procedures. If multiple gases were obtained, the results of the initial sample only were used in this study.

During this study, the uniform defibrillation practice at our hospital was to administer to adult patients the maximum shock that the defibrillator could deliver, repeating this same maximum shock as many times as necessary. (For the one child in the study, the initial shock administered was 2 J/kg.) The University of Iowa Hospital has more than 30 defibrillators of various makes and models. Calibrated energy (based on an assumed 50-Ω resistance) for these defibrillators ranged from 200–400 J. We determined which make and model defibrillator was used on each patient, and calculated the J/kg body weight and J/g heart weight for the shocks applied to each patient. We were unable to calculate the cumulative energy administered, because the total number of shocks administered was uncertain in many patients who received multiple shocks.

As suggested by previous authors,\(^1\)\(^-\)\(^6\) we defined “successful” ventricular defibrillation as the conversion of ventricular fibrillation to any other rhythm, including asystole, by at least one of the shocks. “Unsuccessful” defibrillation was defined as the failure to convert ventricular fibrillation to another rhythm, often despite multiple attempts.

Statistical analysis was initially performed by multivariate analysis using a two-sample Hotelling \( T^2 \) test. A \( p \) value < 0.05 indicated significant differences between the success and failure groups. We then tested the individual variables for significant differences. This analysis (table 1) indicates that the most important determinant of defibrillation success was the delay before the first defibrillatory shock. Other determinants included pH and age, and probably \( \text{PO}_2 \).

To further assess the importance of body weight in
TABLE 1. Comparisons of Successfully vs Unsuccessfully Defibrillated Patients

<table>
<thead>
<tr>
<th></th>
<th>Successful (n = 38)</th>
<th>Unsuccessful (n = 14)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body weight (kg)</td>
<td>71 ± 17</td>
<td>81 ± 26</td>
<td>NS</td>
</tr>
<tr>
<td>Energy/body weight (J/kg)</td>
<td>4.1 ± 1.4</td>
<td>4.2 ± 1.9</td>
<td>NS</td>
</tr>
<tr>
<td>Heart weight (g)</td>
<td>459 ± 183</td>
<td>466 ± 124</td>
<td>NS</td>
</tr>
<tr>
<td>Energy/heart weight (J/g)</td>
<td>0.59 ± 0.22</td>
<td>0.77 ± 0.24</td>
<td>NS (0.07)</td>
</tr>
<tr>
<td>Arterial Po2 (torr)</td>
<td>100 ± 98</td>
<td>40 ± 67</td>
<td>NS (0.06)</td>
</tr>
<tr>
<td>Arterial pH</td>
<td>7.36 ± 0.22</td>
<td>7.23 ± 0.12</td>
<td>0.05</td>
</tr>
<tr>
<td>Delay before defibrillation (min)</td>
<td>7 ± 7</td>
<td>17 ± 13</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Age (years)</td>
<td>61 ± 17</td>
<td>51 ± 13</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>

Values are mean ± sd.
Abbreviation: NS = not significant.

influencing the success of defibrillation, we attempted to control for the time factor. We subdivided the patients into two groups based on the delay before the first shock: short delay (<10 minutes) and long delay (>10 minutes). We then tested the hypothesis that the mean body weight of the successfully defibrillated patients was different from that of the failure patients in the two subgroups, long delay and short delay. This analysis in each subgroup revealed no significant differences in body weight between the successfully defibrillated patients and the failure patients. All results are expressed as mean ± SD.

Results

The results are presented in table 1 and figures 1-4. Fifty-two patients undergoing ventricular defibrillation during 1974-1976 were identified. Of these, 38 were successfully defibrillated, at least temporarily; 14 were never defibrillated.

Body Weight (fig. 1)

One child weighed 8 kg. The adult patients' weights ranged from 43–159 kg. Patients successfully defibrillated had a mean body weight of 71 ± 17 kg; those who were not defibrillated weighed 81 ± 26 kg (NS) (table 1). The heaviest patient, who weighed 159 kg, was not defibrillated; the next heaviest, who weighed 110 kg, was successfully defibrillated.

Energy/Body Weight (fig. 1)

The range was 1.3–7.3 J/kg body weight. The mean successful energy-body weight ratio was 4.1 ± 1.4 J/kg; the unsuccessful energy dose was 4.2 ± 1.9 J/kg (NS). Only three of the seven patients who received more than 6 J/kg body weight were successfully defibrillated.

Heart Weight (fig. 2)

Twenty-three patients were studied at autopsy. The child's heart weighed 58 g. The adult hearts weighed 320–750 g. Patients successfully defibrillated had a mean heart weight of 459 ± 183 g; heart weights of patients not defibrillated were 466 ± 124 g (NS). Three of the four hearts that weighed more than 600 g were successfully defibrillated.

Energy/Heart Weight (fig. 2)

The energy dose used was 0.26–1.25 J/g heart weight. The mean energy-heart weight ratio of the successfully defibrillated patients was 0.59 ± 0.22 J/g; for patients not defibrillated, it was 0.77 ± 0.24 J/g. This difference nearly achieves statistical significance (p = 0.07). Figure 2 shows that of the 11 patients who received more than 0.6 J/g (the median dose), only four were successfully defibrillated, while 10 of the 12 who received less than 0.6 J/kg were successfully defibrillated.
Hypoxia and Acidosis (fig. 3)

Patients who were successfully defibrillated had a \( \text{PO}_2 \) of 100 \( \pm \) 98 torr, while unsuccessfully defibrillated patients had a \( \text{PO}_2 \) of 40 \( \pm \) 67 torr. This difference nearly reached statistical significance \( (p = 0.06) \). Only eight of 15 patients with \( \text{PO}_2 < 40 \) torr could be successfully defibrillated, compared with 21 successes of 22 patients with \( \text{PO}_2 > 40 \) torr. The arterial pH values were: successful 7.36 \( \pm \) 0.22; unsuccessful 7.23 \( \pm \) 0.12 \( (p = 0.05) \). All 14 patients with a pH \( \geq \) 7.4 were successfully defibrillated, whereas eight of 23 with a pH \( < \) 7.4 could not be defibrillated.

Delay Before Defibrillation (fig. 4)

The delay ranged from less than 1 minute to 55 minutes. All patients with a delay exceeding 10 minutes had been brought to our emergency room by ambulance. Some of these long-delay patients were evaluated by emergency medical technicians, who considered them salvageable and began resuscitation efforts immediately. Others suffered cardiopulmonary arrest during ambulance transportation to the hospital. In all these long-delay cases, cardiopulmonary resuscitation was in progress on arrival, but defibrillation had not been attempted before reaching the emergency room. (During the period of this study, defibrillatory shocks were not administered in the ambulances bringing patients to the University of Iowa Hospital.) Patients successfully defibrillated had a mean duration of resuscitation efforts before the first shock of 7 \( \pm \) 7 minutes; patients not defibrillated had a delay of 17 \( \pm \) 13 minutes \( (p < 0.001) \). Only three of 34 patients with a delay \( < \) 10 minutes could not be defibrillated, whereas nine of 18 whose delay was 10 minutes or greater could not be defibrillated.

Age

The ages of the adult patients ranged from 19–81 years; the child was 1 year old. Thirteen of 14 patients older than 70 years of age were successfully defibrillated.

Discussion

Geddes et al.\(^{10} \) showed that the threshold electrical energy dose required for defibrillation in animals was dependent on body weight. Applying this concept to humans, Tacker et al.\(^{1} \) reviewed ventricular defibrilla-

\[ N = 37 \text{ Patients} \]

\[ \text{Hypoxia} \]

\[ \begin{array}{ccc}
\text{Successful} & \text{Unsuccessful} \\
\end{array} \]

\[ \text{Defibrillation} & \text{Defibrillation} \\
\end{array} \]

\[ \text{Acidosis} \]

\[ \begin{array}{ccc}
\text{Successful} & \text{Unsuccessful} \\
\end{array} \]

\[ \text{Defibrillation} & \text{Defibrillation} \\
\end{array} \]

\[ \text{FIGURE 2. Relationship of heart weight and energy/heart weight to defibrillation success. Three of the four large hearts (> 600 g) were successfully defibrillated. However, a high energy/g heart weight dose appeared deleterious — only four of 11 patients receiving > 0.6 J/g heart weight could be defibrillated.} \]

\[ \text{FIGURE 3. Relationship of metabolic abnormalities to defibrillation success. Unsuccessful defibrillation was almost always (one exception) associated with both acidosis and hypoxia.} \]
tion attempts at Baylor University and the Mayo Clinic. They found that the percentage of patients successfully defibrillated (using defibrillators providing up to 300 J calibrated energy) decreased with increasing body weight. They concluded that a maximum amount of 300 J energy is inadequate to defibrillate at least 35% of patients who weighed 50–110 kg, and recommended the construction of higher-output defibrillators for use in adult patients if initial lower-energy shocks fail. Similar results have subsequently been reported by Collins et al. However, Tacker's study involved a relatively small number of patients, especially at the upper ranges of body weight. Thus, although only 33% of patients weighing over 90 kg were defibrillated, there were only six (of 111) patients in this group. Of the 97 patients whose weights were 50–90 kg, the average success rate was about 70%, and examination of the published figure does not suggest a decreasing success rate with increasing body weight within this range.

Another challenge to the concept that high-energy doses are required in adults comes from the work of Pantridge et al., who prospectively studied the efficacy of multiple low-energy shocks in reverting ventricular fibrillation. Using shocks of 150 or 165 J, they found that 80 of 82 episodes of ventricular fibrillation responded to one or two shocks, and that the outcome of such therapy was unrelated to body weight; in fact, five of their successful defibrillations were in patients weighing 90–100 kg. Additional corroborating studies have subsequently been reported by Sipes et al. and Campbell et al. These studies imply that defibrillation should always be attempted initially with one or more low-energy shocks, increasing the energy in the unusual situation where multiple low-energy shocks fail. The reported differences in the effectiveness of relatively low-energy shocks in these studies may in part be explained by the differences in the incidence of primary ventricular fibrillation (i.e., fibrillation in the absence of congestive failure or cardiogenic shock, and presumably, therefore, more responsive to defibrillation) and also by differences in the duration of time of ventricular fibrillation before the first DC shock was applied.

Our study does not clearly support the concept of a weight-related defibrillation dose, since there was no significant difference between the weights of the successfully and unsuccessfully defibrillated groups. However, while the overall defibrillation success rate in this study was 73%, the success rate for heavy patients (>90 kg) was only 50%. These results are very similar to those of Tacker et al., but in our study, too, the number of patients in the heavy group was very small. Moreover, the three heavy patients in our study who could not be successfully defibrillated had severe metabolic abnormalities. There may be some threshold weight level above which presently available defibrillators cannot deliver adequate current to defibrillate, but data from many more heavy patients are required to answer this question.

Examination of the energy data raises the question of whether a high energy-heart weight ratio was deleterious. Although the heart weight itself appeared to make no difference to defibrillation success, patients receiving more than the median dose of 0.6 J/g heart weight had a success rate of only 37%, while in those receiving less than 0.6 J/g, defibrillatory shocks were 83% successful (fig. 2). Repeated shocks using extremely high energy levels have been shown to induce myocardial necrosis in animals, but a threshold energy above which cardiac damage appears in humans has not been established. In patients who received a high dose of energy per gram of heart weight, deleterious electrophysiologic alterations may have resulted from the electric shock itself, which contributed to failure to defibrillate most of the patients in this group. If so, this would be an argument against the initial use of high-energy shocks for defibrillation. Excessive energy per gram of heart weight has not previously been considered a cause of defibrillation failure, but future studies should evaluate this possibility.

Metabolic abnormalities have not been extensively evaluated as a cause for defibrillation failure. Brooks and Feldman described two patients with severe metabolic acidosis who could be defibrillated only after bicarbonate therapy. However, in experimental studies, Redding and Pearson and Yakaitis et al. could not demonstrate significant effects of acid-base imbalance or hypoxia on energy requirements for defibrillation. Because of this limited and contradictory data, we evaluated metabolic factors in clinical defibrillation. This study suggests that acidosis, hypoxia and a prolonged delay before the first defibrillatory shock had a major adverse effect on
defibrillation success. These three conditions tended to accompany each other, especially in patients subjected to lengthy resuscitation attempts before arriving at the hospital, who received their first shock in the emergency room. Programs to train emergency medical technicians fully and provide them with adequate equipment to render advanced life support, including immediate defibrillation, when appropriate, should reduce the incidence of this often-fatal triad.

It is possible that reported failures to defibrillate heavy patients may, at least in part, be due to a higher incidence of acidosis and hypoxia, since effective ventilation and closed-chest cardiac compression is predictably more difficult to achieve in obese or large patients. In fact, the three heavy (>90 kg) patients in our study who could not be defibrillated were all acidic and hypoxic; the metabolic abnormalities in these three heavy patients were probably exacerbated by the fact that each had undergone more than 10 minutes of cardiopulmonary resuscitation before the first defibrillatory shock. Initially unsuccessful defibrillation in such patients may be responsive to correction of metabolic abnormalities. Future studies of electrical energy dose should also give data on the arterial blood gases of the patients, whenever available.

The limitations of this study should be clearly acknowledged. It is a retrospective investigation. Although the blood gas determinations were obtained in most patients after initial therapy with oxygen and bicarbonate (administered according to the American Heart Association standards14), in some patients the exact time of blood gas sampling was unrecorded and may have preceded therapy. Blood gas data were not obtained or recorded in every patient. Since the heart weight determinations were based on autopsy data, they are available only in those patients who ultimately died, which may bias the results. Future prospective studies of ventricular defibrillation may resolve these uncertainties.

In summary, we found no clear relationship between body weight and ability to defibrillate, although heavy patients may have a lower defibrillation success rate. High energy per gram of heart weight may be deleterious. Acidosis, hypoxia and a prolonged delay before defibrillation are factors that have an adverse effect on the success of ventricular defibrillation.

Acknowledgment

We acknowledge the advice of Dr. W.A. Tacker, Purdue University, and the statistical assistance of Pat Hu and Dr. Judy A. Bean, University of Iowa.

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Factors influencing the success of ventricular defibrillation in man.
R E Kerber and W Sarnat

Circulation. 1979;60:226-230
doi: 10.1161/01.CIR.60.2.226

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

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