Low Energy Synchronous Transcatheter Cardioversion of Atrial Flutter/Fibrillation in the Dog

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The feasibility and effectiveness of low energy synchronous transcatheter cardioversion of atrial flutter and fibrillation were examined in dogs with tachyinduced pericarditis. A conventional electrode catheter was positioned transvenously in the right atrial appendage. Atrial flutter/fibrillation was induced by using the train pulse method, and the tachyarrhythmia-inducing threshold was determined. The minimal effective cardioversion energy levels were compared in three different cardioversion methods: method A = delivery of shock between the proximal electrode (cathode) and the backplate (anode), method B = delivery between the proximal electrode (cathode) and the distal electrode (anode) and method C = conventional external cardioversion.

In both methods A and B, all 149 cardioversion attempts were successful with shocks of ≤5 J. Shocks of ≤1 J resulted in successful cardioversion in 57 (70%) of 81 attempts, 50 (74%) of 68 attempts and 5 (12%) of 41 attempts with methods A, B and C, respectively. The mean minimal effective cardioversion energy levels were not significantly different between methods A and B (0.62 ± 0.67 versus 0.58 ± 0.71 J). Transcatheter cardioversion decreased the defibrillation threshold 3- to 75-fold (mean 6- to 7-fold) from that of transthoracic cardioversion. The defibrillation threshold was not influenced by the inducibility of atrial flutter/fibrillation. There were no complications of heart block, ventricular fibrillation or pathologic evidence of severe shock-induced atrial injury.

Thus, low energy synchronous transcatheter cardioversion of atrial flutter/fibrillation is considered feasible and effective. This technique may also be useful in managing the atrial flutter/fibrillation that can occur during electrophysiologic studies.

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Paroxysmal atrial tachyarrhythmias such as atrial flutter and atrial fibrillation occur commonly in humans and therapeutic intervention is often necessary (1). Direct current external cardioversion has been recognized to be an effective treatment for restoring sinus rhythm (2-5). However, high energy electrical shocks are traumatic to the body and may result in skin burns and myocardial injury. Moreover, heavy sedation is usually required before energy delivery (6,7).

For more than a decade, the feasibility of low energy cardioversion of atrial tachyarrhythmias has been demonstrated with use of a transvenous electrode catheter positioned within the right atrium (8-11). The investigators (8-11) obtained only very low success rates of cardioversion using low energy levels ranging from 0.01 to 5 J in both dogs and humans. Recently, Levy et al. (12) devised a new technique of internal transcatheter cardioversion of chronic atrial fibrillation using high energy shocks (200 to 300 J) without damaging the atrium or the atrioventricular (AV) conduction system. However, they did not specify the minimal effective energy levels required for cardioversion in each patient or the exchange rate of energy levels between the transcatheter cardioversion and the external transthoracic cardioversion.

We designed this study to 1) evaluate the minimal effective cardioversion energy levels of transcatheter cardioversion in acute atrial flutter/fibrillation with use of a conventional electrode catheter; 2) compare the results of the transcatheter technique with those of the transthoracic technique; 3) assess the effect of the anode position at two different sites (the endocardial electrode and the external body surface) in transcatheter cardioversion; and 4) examine whether the inducibility of atrial flutter/fibrillation influenced the minimal effective cardioversion energy levels.
Methods

Experimental preparation. Procedures were conducted in accordance with the guidelines outlined in the "Position of the American Heart Association on Research Animal Use" adopted November 11, 1984 by the American Heart Association. Eighteen adult mongrel dogs weighing between 9 and 20 kg were anesthetized with intravenous sodium pentobarbital (30 mg/kg body weight). After endotracheal intubation, the dogs were ventilated by means of a Harvard respirator. The chest was opened by a right thoracotomy through the fifth intercostal space using an aseptic technique. Sterile talc (20 ml) was injected intrapericardially to induce sterile pericarditis, and the pericardium and chest were closed.

Study preparation. Four days after thoracotomy, the dogs were again anesthetized with intravenous sodium pentobarbital (30 mg/kg), intubated and mechanically ventilated with room air. A quadripolar conventional 6F catheter was introduced through a surgical cutdown of the femoral vein and positioned within the right atrial appendage under fluoroscopic guidance. The distal electrode pair was used for pacing to initiate the tachycardia and the proximal pair was used for recording the atrial electrogram. When transcatheter cardioversion was performed, a distal electrode (pole 1) was used as the anode and a proximal electrode (pole 4) that was floating in the atrial cavity was used as the cathode. Surface electrocardiographic (ECG) lead II and intracardiac electrograms were recorded at a paper speed of 100 mm/s (San Ei BM14).

Atrial flutter/fibrillation was induced by a train pulse method that delivered a train of rectangular pulses (4 ms, 100 Hz) during a vulnerable period of the atrium through the distal electrode pair (Fukuda Denshi BC-02A stimulator). The train pulses were begun 50 ms after the onset of the P wave and continued to the end of the S wave. The current was increased in mA increments until atrial flutter/fibrillation occurred (Fig. 1).

The specially designed cardioverter (Fukuda Denshi FC 710) delivered a truncated exponential waveform 6 ms in duration at 12 energy levels: 0.01, 0.05, 0.1, 0.25, 0.5, 0.75, 1.0, 1.5, 2.0, 3.0, 4.0 and 5.0 J. All cardioversion energy deliveries were synchronized to the QRS complex. Beginning with 0.01 J, shocks of progressively increasing energy were delivered until atrial flutter/fibrillation was terminated (Fig. 2). Atrial flutter/fibrillation was reinitiated and the same sequence repeated three to five times to determine the minimal energy required to reproducibly terminate the tachycardia. An interval of 5 min was allowed between each cardioversion attempt. The correlation between the minimal current necessary to initiate atrial flutter/fibrillation and the minimal energy needed to terminate them was examined.

Cardioversion protocol. Three methods of cardioversion were tested to compare each of the minimal energy levels necessary to terminate atrial flutter/fibrillation in all dogs:

- Method A = delivery of shocks through a proximal electrode (pole 4) as the cathode and the backplate as the anode;
- Method B = delivery of shocks between a proximal electrode (pole 4) as the cathode and a distal one (pole 1) as the anode and method C = external transthoracic cardioversion.

Each of the three methods was tested in random order. In all dogs, the reproducibility of the minimal energy needed to initiate atrial flutter/fibrillation determined through all cardioversion series was evaluated, as was the reproducibility of the minimal energy necessary to terminate atrial flutter/fibrillation in method A.

Atrial pathologic examination. Gross and histologic studies of the atrium were performed in three dogs without talc-induced pericarditis with use of methods A and B, respectively. Ten intraatrial shocks of 5 J were delivered during sinus rhythm.

Definitions. 1) Atrial flutter/fibrillation: atrial arrhythmia where the cycle length was <200 ms and the duration was >30 s.
2) Successful cardioversion: conversion to normal sinus rhythm within 2 s after energy delivery.
3) Atrial flutter/fibrillation threshold: the minimal current in milliamperes required to produce atrial flutter/fibrillation.
4) Defibrillation threshold: the minimal energy in joules required to terminate atrial flutter/fibrillation.

Results

Atrial flutter/fibrillation characteristics (Table 1). One hundred ninety episodes of atrial flutter or fibrillation (156 of atrial flutter and 34 of atrial fibrillation) were initiated by the
train pulse methods in the 18 dogs. For all tachyarrhythmias, the mean atrial cycle length ranged from 100 to 180 ms. The mean atrial cycle length of atrial flutter/fibrillation induced in an individual dog was generally reproducible with standard deviations ranging between 1.2 to 15.1 ms; the atrial flutter/fibrillation threshold was also reproducible, with standard deviations ranging from 2.3 to 10.3 mA.

Cardioversion results (Fig. 3). In method A, all 81 cardioversion attempts were successful with shocks of ≤5 J. Shocks of ≤1 J resulted in successful cardioversion in 57 (70%) and shocks of ≤0.5 J resulted in successful cardioversion in 29 (36%). In method B, successful cardioversion also occurred in all 68 attempts with shocks of ≤5 J. Shocks of ≤1 J resulted in successful cardioversion in 50 (74%) and shocks of ≤0.5 J resulted in successful cardioversion in 32 (47%). In method C, no successful cardioversion resulted from shocks of ≤0.5 J in 41 attempts. Shocks of ≤1 J resulted in successful cardioversion in only 5 (12%).

Comparison of defibrillation threshold (Fig. 4). The minimal defibrillation threshold in method B tended to be lower than that in method A, but this difference was not statistically significant (mean 0.62 ± 0.67 versus 0.58 ± 0.71 J, p = NS). In method C, a wide range of defibrillation thresholds was observed (range 0.75 to 20 J, mean 4.0 ± 3.52). The threshold in method C was significantly higher (range 3- to 75-fold) than the threshold in methods A and B. The defibrillation threshold of transcatheter cardioversion (method A) was generally reproducible, with standard deviations ranging between 0.2 and 1.4 J (Table I).

There was no significant correlation between the atrial flutter/fibrillation threshold and the defibrillation threshold in method A (r = 0.085). Accordingly, the defibrillation thresholds were not influenced by the inducibility of atrial flutter/fibrillation.

Figure 3. Comparison of the success rate of cardioversion for three cardioversion methods. In both methods A and B, all 149 attempts were successful using ≤5 J. DFT = defibrillation threshold.

Table I. Reproducibility of Induced Atrial Flutter/Fibrillation, Atrial Flutter/Fibrillation Threshold and Defibrillation Threshold in 18 Dogs

<table>
<thead>
<tr>
<th>Dog No.</th>
<th>Mean Atrial CL of AFF (ms)</th>
<th>No. of AFF</th>
<th>Mean AFFT (mA)</th>
<th>Mean DFT in Method A (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>110 ± 4.2</td>
<td>11</td>
<td>4.9 ± 3.1</td>
<td>2.3 ± 1.4</td>
</tr>
<tr>
<td>2</td>
<td>148 ± 10.5</td>
<td>10</td>
<td>5.5 ± 2.3</td>
<td>0.5 ± 0.2</td>
</tr>
<tr>
<td>3</td>
<td>122 ± 6.7</td>
<td>10</td>
<td>18.6 ± 7.8</td>
<td>1.0 ± 0.5</td>
</tr>
<tr>
<td>4</td>
<td>140 ± 2.2</td>
<td>10</td>
<td>9.4 ± 2.3</td>
<td>0.9 ± 0.6</td>
</tr>
<tr>
<td>5</td>
<td>134 ± 5.2</td>
<td>10</td>
<td>12.7 ± 6.4</td>
<td>0.5 ± 0.5</td>
</tr>
<tr>
<td>6</td>
<td>106 ± 15.1</td>
<td>10</td>
<td>12.4 ± 2.8</td>
<td>3.4 ± 1.4</td>
</tr>
<tr>
<td>7</td>
<td>130 ± 5.0</td>
<td>12</td>
<td>21.8 ± 7.6</td>
<td>0.3 ± 0.2</td>
</tr>
<tr>
<td>8</td>
<td>136 ± 1.2</td>
<td>12</td>
<td>13.3 ± 2.4</td>
<td>0.2 ± 0.3</td>
</tr>
<tr>
<td>9</td>
<td>140 ± 8.3</td>
<td>9</td>
<td>17.9 ± 6.3</td>
<td>0.4 ± 0.2</td>
</tr>
<tr>
<td>10</td>
<td>135 ± 2.4</td>
<td>10</td>
<td>12.1 ± 2.9</td>
<td>0.7 ± 0.4</td>
</tr>
<tr>
<td>11</td>
<td>132 ± 3.1</td>
<td>10</td>
<td>45.9 ± 5.6</td>
<td>0.7 ± 0.5</td>
</tr>
<tr>
<td>12</td>
<td>141 ± 3.7</td>
<td>10</td>
<td>73.4 ± 9.0</td>
<td>0.7 ± 0.2</td>
</tr>
<tr>
<td>13</td>
<td>142 ± 4.2</td>
<td>10</td>
<td>24.2 ± 3.2</td>
<td>0.6 ± 0.2</td>
</tr>
<tr>
<td>14</td>
<td>108 ± 3.3</td>
<td>9</td>
<td>67.1 ± 7.6</td>
<td>1.5 ± 0.5</td>
</tr>
<tr>
<td>15</td>
<td>144 ± 5.2</td>
<td>16</td>
<td>10.9 ± 4.1</td>
<td>0.7 ± 0.5</td>
</tr>
<tr>
<td>16</td>
<td>148 ± 4.6</td>
<td>10</td>
<td>34.4 ± 9.6</td>
<td>0.5 ± 0.4</td>
</tr>
<tr>
<td>17</td>
<td>109 ± 4.4</td>
<td>9</td>
<td>52.7 ± 10.3</td>
<td>2.2 ± 1.0</td>
</tr>
<tr>
<td>18</td>
<td>119 ± 1.9</td>
<td>11</td>
<td>51.5 ± 8.7</td>
<td>1.2 ± 0.5</td>
</tr>
</tbody>
</table>

AFF = atrial fluter/fibrillation; AFFT = atrial flutter/fibrillation threshold; CL = cycle length; DFT = defibrillation threshold.
Figure 4. Comparison of the minimal defibrillation threshold (DFT) for three cardioversion methods. There was no significant difference between methods A and B (0.62 ± 0.67 versus 0.58 ± 0.71 J, p = NS). In method C, the defibrillation threshold was significantly higher than that in methods A and B (p < 0.01).

Complications. There were no episodes of ventricular fibrillation, AV conduction disturbance or delayed sinus recovery >1.5 s after shocks.

Atrial pathology. In method A, none of the three dogs revealed any gross or histologic evidence of shock-induced injury. Conversely, in method B, all three dogs revealed small foci of subendocardial necrosis at the cathode site in the right atrial appendage.

Discussion

Previous studies. Mirowski et al. (8) first introduced the concept of transvenous catheter cardioversion of atrial tachyarrhythmias induced by the administration of acetylcholine in dogs. Benditt et al. (9) emphasized the importance of large surface area electrodes for successful transvenous cardioversion of atrial tachyarrhythmias. In their studies, atrial tachyarrhythmias was terminated in 23% of trials and a quadrifilar catheter (USCI) positioned in the right atrial appendage failed to terminate tachyarrhythmias in dogs. Nathan et al. (10) reported that atrial shocks were unsuccessful for cardioversion of atrial flutter/fibrillation in humans, but did not specify the position of the anode. Using the same catheter, Dunbar et al. (11) demonstrated that low energy (ranging from 0.01 to 5 J) cardioversion of atrial tachyarrhythmias was feasible in dogs with tach-induced pericarditis, with a cardioversion success rate of 26%.

Recently, Levy et al. (12) developed a new technique of transcatheter cardioversion of chronic atrial fibrillation using high energy shocks (200 to 300 J). It was performed by pulling back the catheter from the AV junction, settling it just below the site of the His bundle recording and delivering the energy between the proximal electrode of a conventional catheter as the cathode and the backplate as the anode. These authors (12) observed that transcatheter shock immediately restored sinus rhythm without injuring the AV conduction system or the atrial wall in 9 of 10 patients. If the electrode adopted as the cathode was in contact with the atrial wall or the AV junction as in the methods of previous studies, electrical shock might ablate these areas. Accordingly, we decided to use the proximal electrode, which was floating in the atrial cavity and not in contact with the atrial wall, as the cathode. We also chose a conventional pacing electrode with a surface area of 8 to 10 mm², in contrast to a wide surface area of 1.25 cm² (Medtronic 6880) used in the study of Nathan et al. (10). These differences in methodology may account for the discrepancy between their work and our results. We considered that the cathode position was a more critical factor for successful cardioversion than the surface area of the electrode.

In the present study, the site of the anode, either the proximal electrode or the backplate, did not significantly influence the efficacy of defibrillation. It appeared to offer no advantage over the single electrode configuration. This finding was similar to the results obtained by Jackman and Zipes (13), in which the energy requirements for cardioversion or defibrillation of ventricular tachycardia were reduced (20- to 250-fold) by the use of wide surface area epicardial electrodes compared with endocardial electrodes. These authors (13) explained their observations by a short-circuiting effect, whereby the current was probably lost to the blood pool between the cathode and anode of the catheter electrodes. Yee et al. (14) noted that the optimal position of the electrode as an anode was less critical so long as sufficient electrode surface area was present.

Clinical implications. We demonstrated that low energy transcatheter cardioversion was a feasible and effective method for terminating atrial flutter/fibrillation in dogs. In addition to its usefulness in an acute cardiac care setting, this technique could be adopted for use during electrophysiologic studies when pacing techniques are ineffective for terminating tachyarrhythmias. Moreover, this technique could be an alternative to infusion of antiarrhythmic drugs and general anesthetic drugs before conventional direct current cardioversion, which might interfere with further testing procedures (9). Further studies are necessary, however, to assess the applicability of this technique in humans.

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References


