Titration energy cardioversion of patients on digitalis

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Elective cardioversion with titrated energy was carried out under diazepam anaesthesia (38 procedures) in 26 patients on digitalis who presented with supraventricular or ventricular arrhythmias. Low energy shocks were given to establish the absence of latent digitalis intoxication, not unmasked by previous carotid sinus massage, and to restore sinus rhythm with the lowest possible energy discharge.

In the absence of digitalis overdosage, titrated energy cardioversion restored sinus rhythm, at least temporarily, without dangerous ventricular arrhythmias. In one patient this precaution was neglected: a shock of 200 Ws provoked ventricular tachycardia.

We present experimental and clinical evidence for the safety and effectiveness of titrated energy cardioversion in patients on digitalis.

Cardioversion is a technique used to convert a sustained supraventricular arrhythmia into normal sinus rhythm by applying to the heart a direct current shock triggered by the QRS complex of the electrocardiogram (Lown, Amarasingham, and Neuman, 1962; Killip, 1963; Lown, 1967; Resnekov, 1974). The ideal waveform of the discharge has been carefully investigated (Lown et al., 1962); its energy content is usually expressed in watts-seconds (Ws).

Soon after cardioversion was adopted in clinical practice various centres reported that cardioversion of patients on digitalis could produce an array of ventricular arrhythmias, including fatal ventricular fibrillation (Lemberg et al., 1964; Rabbino, Likoff, and Dreifus, 1964; Ross, 1964; Paulk and Hurst, 1965; Robinson and Wagner, 1965). For this reason, it is now widely recommended (Chung, 1969; Resnekov, 1974) that digitalis should be discontinued for several days before attempting cardioversion. When the severity of the clinical condition precludes discontinuance of digitalis therapy, this is widely regarded as a contraindication to cardioversion. This form of treatment is, therefore, withheld in the more seriously failing heart, where the restoration of an effective atrial contraction might importantly contribute to haemodynamic improvement (Killip and Baer, 1966).

The incidence of ventricular arrhythmias induced by cardioversion in patients on digitalis is directly related to the energy content of the electrical discharge (Kleiger and Lown, 1966); we, therefore, investigated the use of titrated energy in safely restoring sinus rhythm in patients on digitalis.

Subjects and methods

Patients
Thirty-eight titrated energy cardioversions were carried out in 26 patients on digitalis: pertinent details are listed in the table. The procedure was carried out under diazepam anaesthesia (Guiney and Lown, 1972).

Procedure
Direct current triggered defibrillators of various makes were used. A flat paddle was positioned below the inferior angle of the left scapula, the other was pressed over the third and fourth intercostal spaces, at the left sternal border (Lown, 1967). This anteroposterior paddle positioning ensures the best delivery of the energy content of the electrical discharge to the heart (Tacker et al., 1974).

Starting with the lowest energy setting on the defibrillator, triggered electrical shocks were delivered with increasing energy content in each successive discharge until sinus rhythm returned, or until ventricular arrhythmias occurred, indicating that further energy increments might be dangerous. This procedure is described as titrated energy cardioversion, implying
that the energy used for cardioversion was titrated to
the need of the individual patient.

The usual sequence was (Ws): 12-5–25–50–100–200. Energies higher than 200 Ws were never necessary.

Precautions
Cardioversion was always carried out in an intensive care area where drugs and equipment required for successful resuscitation were immediately available. An intravenous line was used for diazepam anaesthesia and for intravenous antiarrhythmic medication if needed: two syringes each containing 50 mg lignocaine were ready for emergency use.

Carotid sinus massage was used to establish the nature of the arrhythmia and to uncover latent digitalis intoxication in some cases (Lown et al., 1972). Paroxysmal atrial tachycardia with block presenting in a patient on digitalis was regarded as an absolute contraindication to elective cardioversion because the risks of DC shock are known to be high in these patients (Vassaux and Lown, 1969). Digitalis overdosage was assumed when carotid sinus massage evoked ventricular bigeminy or ventricular extra-systoles occurring early after the vagal stimulus (Fig. 1); escape mechanisms were regarded as a normal response to this manoeuvre (Lown et al., 1972).

Since hypokalaemia may increase the frequency of occurrence of arrhythmias in patients on digitalis (Lown and Wittenberg, 1968; Lown et al., 1972), potassium blood level was always measured immediately before cardioversion. Intravenous potassium supplements were given if serum potassium concentration was below 3.8 mmol/l.

The electrocardiogram was recorded on paper during each electrical discharge. The occurrence of ventricular arrhythmias after a shock was regarded as a sign of latent digitalis intoxication and an indication for not proceeding with the next energy increment of the titrated energy cardioversion procedure.

Results
The effectiveness and possible toxic effects of each cardioversion procedure are summarized in the Table. Only one patient (Case 3) developed a ventricular arrhythmia after cardioversion (Fig. 2): no digitalis was given during the next 24 hours, and titrated energy cardioversion was then successful. No other ventricular arrhythmias induced by a DC shock were observed in these patients.

A curious phenomenon which we have observed twice is shown in Fig. 3. This is delayed reversion of a supraventricular arrhythmia to sinus rhythm within 30 seconds after a low energy discharge. In both cases the morphology of the P waves changed, and the ventricular rate decreased slightly. The arrhythmia had been continuously present for 3 and 5 hours in these 2 patients, and did not recur on maintenance digitalis therapy. This observation suggests that the electrical discharge may sometimes bring about reversion to sinus rhythm by a mechanism different from a mere depolarization of all cardiac fibres (Lown et al., 1962), probably by transforming a stable supraventricular arrhythmia into an unstable mechanism which later terminates spontaneously.

Discussion
The proven effectiveness of cardioversion for supraventricular arrhythmias has been marred by documented cases of fatality caused by the procedure, when used in patients on digitalis (Lemberg et al., 1964; Rabbino et al., 1964; Ross, 1964; Paulk and Hurst, 1965; Robinson and Wagner, 1965). This has prompted extensive electrophysiological research in the experimental animal.

It has long been known that electric current may provoke ventricular fibrillation (Prevost and Battelli, 1899). However, the discovery of the vulnerable period in the electrocardiogram has led to a better understanding of the mechanisms of its onset (Wiggers and Wegria, 1940). Acute myocardial ischaemia greatly reduces the fibrillatory threshold and this is probably the most usual mechanism of sudden death (Wolff, Veith, and Lown, 1968).

FIG. 1 Bigeminy elicited by carotid sinus massage (CSM) in a patient with rheumatic heart disease and digitalis overdose.
Digitalis exerts similar effects (Lown, Kleiger, and Williams, 1965; Lown and Wittenberg, 1968): in dogs an electrical shock applied during the vulnerable period elicits arrhythmias, such as ventricular tachycardia and/or ventricular fibrillation, similar to those caused by digitalis overdosage. The observations made under experimental conditions are in fact exactly reproduced in clinical practice: in patients given digitalis, cardioversion may be lethal.

Low energy cardioversion discharges can, therefore, be used for a dual purpose: to convert the arrhythmia, and to uncover latent digitalis toxicity (Castellanos et al., 1967; Lown, Cannon, and Rossi, 1967; Hagemeijer and Lown, 1970). Rhythm strips recorded during low energy cardioversion may show ventricular arrhythmias, warning that further increments of the energy content of the discharge may lead to a more menacing type of ventricular arrhythmia. Initiating cardioversion with a low energy shock is, thus, a safeguard against the dangerous consequences of higher energies applied to an overdigitalized heart. Titrated energy cardioversion may safely be attempted in patients on digitalis; this is particularly important when resumption of sinus rhythm may be of crucial importance for the haemodynamic improvement of a patient in heart failure (Killip and Baer, 1966).

Titrated energy cardioversion not only serves as an indicator of impending malignant ventricular arrhythmias, but is also effective, both in ventricular and in supraventricular rhythm disturbances. The minimum energy content of an effective DC shock may be low. Ventricular tachycardia may revert after a discharge of only 1 Ws (Table). This is not surprising considering the occasional effectiveness of a chest thump in reverting ventricular flutter (Pennington, Taylor, and Lown, 1970). Atrial flutter requires energy levels of 10 to 25 Ws (Guiney and Lown, 1972), and atrial fibrillation from 50 to 200 Ws.

The procedure is perfectly safe if attention is paid to all the details described earlier: correct anaesthesia, avoidance of hurry, control of serum potassium, careful analysis of the electrocardiogram recorded after each discharge, availability of trained personnel, and adequate monitoring of the patient.

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**FIG. 2** Short run of ventricular tachycardia after a 200 Ws discharge in a patient with rheumatic heart disease, hypertension, and a maintenance dose of digoxin in 0.375 mg/day.

**FIG. 3** Delayed reversion to sinus rhythm 17s after a 12.5 Ws discharge in a patient with a myocardial infarct 32 hours previously who was treated with intravenous ouabain 0.5 mg given over a 4-hour period. After the DC shock the configuration of P waves was different and the ventricular rate had slowed from 135/min to 120/min, before reversion to sinus rhythm.
### Table 1: Results of 38 titrated energy cardioversions in 26 patients given digitalis

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yr)</th>
<th>Sex</th>
<th>Disease</th>
<th>Arrhythmia</th>
<th>Digitalis (mg)</th>
<th>Other drugs (mg)</th>
<th>Energy (Ws) of discharges</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24</td>
<td>M</td>
<td>RHD</td>
<td>A fib</td>
<td>mD 0.25</td>
<td>—</td>
<td>10</td>
<td>NSR</td>
</tr>
<tr>
<td>2</td>
<td>40</td>
<td>M</td>
<td>RHD</td>
<td>AF</td>
<td>mD 0.25</td>
<td>—</td>
<td>25-50-100</td>
<td>AF</td>
</tr>
<tr>
<td>3</td>
<td>59</td>
<td>M</td>
<td>RHD</td>
<td>A fib</td>
<td>mD 0.375</td>
<td>—</td>
<td>200</td>
<td>VT-&gt;A fib</td>
</tr>
<tr>
<td>4</td>
<td>48</td>
<td>F</td>
<td>RHD</td>
<td>A fib</td>
<td>mD 0.25</td>
<td>—</td>
<td>12.5-25-50-100-200</td>
<td>NSR-&gt;A fib</td>
</tr>
<tr>
<td>5</td>
<td>58</td>
<td>M</td>
<td>Sick sinus syndrome</td>
<td>A fib</td>
<td>mD 0.25</td>
<td>—</td>
<td>12.5-25-50-100-NSR</td>
<td>NSR-&gt;A fib</td>
</tr>
<tr>
<td>6</td>
<td>67</td>
<td>M</td>
<td>Sick sinus syndrome</td>
<td>A fib</td>
<td>mD 0.25</td>
<td>—</td>
<td>12.5-25-50-100-NSR</td>
<td>NSR-&gt;A fib</td>
</tr>
<tr>
<td>7</td>
<td>54</td>
<td>M</td>
<td>Sick sinus syndrome</td>
<td>A fib</td>
<td>mD 0.25</td>
<td>Q 600 (1 h)</td>
<td>12.5-25-50-100-200</td>
<td>NSR-&gt;A fib</td>
</tr>
<tr>
<td>8</td>
<td>25</td>
<td>F</td>
<td>PAT</td>
<td>PAT</td>
<td>O 0.975 (5 h)</td>
<td>—</td>
<td>12.5</td>
<td>NSR</td>
</tr>
<tr>
<td>9</td>
<td>24</td>
<td>F</td>
<td>PAT</td>
<td>PAT</td>
<td>mD 0.25</td>
<td>—</td>
<td>12.5</td>
<td>NSR</td>
</tr>
<tr>
<td>10</td>
<td>59</td>
<td>M</td>
<td>WPW</td>
<td>A fib</td>
<td>O 0.50 (3 h)</td>
<td>—</td>
<td>12.5-25-50-100-NSR</td>
<td>NSR-&gt;A fib</td>
</tr>
<tr>
<td>11</td>
<td>71</td>
<td>M</td>
<td>Bone surgery</td>
<td>A fib</td>
<td>O 1-50 (16 h)</td>
<td>—</td>
<td>12.5-25-50-NSR</td>
<td>NSR</td>
</tr>
<tr>
<td>12</td>
<td>67</td>
<td>F</td>
<td>Hypertension</td>
<td>A fib</td>
<td>mD 0.25</td>
<td>—</td>
<td>12.5-25-50-100-200</td>
<td>NSR</td>
</tr>
<tr>
<td>13</td>
<td>17</td>
<td>M</td>
<td>Transposition</td>
<td>A fib</td>
<td>mD 0.375</td>
<td>mPr 200</td>
<td>25-50-100</td>
<td>NSR</td>
</tr>
<tr>
<td>14</td>
<td>15</td>
<td>M</td>
<td>Rastelli operation</td>
<td>AF</td>
<td>mD 0.25</td>
<td>mQ 1000</td>
<td>12.5-25-50-200-NSR</td>
<td>NSR</td>
</tr>
<tr>
<td>15</td>
<td>58</td>
<td>M</td>
<td>CAD</td>
<td>AF</td>
<td>O 1-00 (18 h)</td>
<td>—</td>
<td>12.5-25-50-200 NSR</td>
<td>NSR</td>
</tr>
<tr>
<td>16</td>
<td>55</td>
<td>M</td>
<td>CAD</td>
<td>AF</td>
<td>mD 0.25</td>
<td>Q 200 (2 h)</td>
<td>12.5</td>
<td>NSR</td>
</tr>
<tr>
<td>17</td>
<td>49</td>
<td>M</td>
<td>CAD</td>
<td>A fib</td>
<td>mD 0.25</td>
<td>Q 400 (1 h)</td>
<td>12.5-25-50-200-100-200</td>
<td>NSR-&gt;A fib</td>
</tr>
<tr>
<td>18</td>
<td>56</td>
<td>M</td>
<td>CAD</td>
<td>AF</td>
<td>O 1-00 (12 h)</td>
<td>—</td>
<td>12.5-25-50-100-200</td>
<td>NSR-&gt;A fib</td>
</tr>
<tr>
<td>19</td>
<td>48</td>
<td>M</td>
<td>AMI</td>
<td>A fib</td>
<td>O 0.75 (10 h)</td>
<td>—</td>
<td>12.5-25-50-50-100</td>
<td>NSR</td>
</tr>
<tr>
<td>20</td>
<td>54</td>
<td>M</td>
<td>AMI</td>
<td>AF</td>
<td>O 1-00 (16 h)</td>
<td>—</td>
<td>12.5-25-50-200 NSR</td>
<td>NSR</td>
</tr>
<tr>
<td>21</td>
<td>64</td>
<td>F</td>
<td>AMI</td>
<td>A fib</td>
<td>O 1-75 (20 h)</td>
<td>—</td>
<td>12.5-25-50-100-200</td>
<td>NSR</td>
</tr>
<tr>
<td>22</td>
<td>78</td>
<td>F</td>
<td>AMI</td>
<td>AF</td>
<td>O 0.50 (4 h)</td>
<td>—</td>
<td>12.5</td>
<td>NSR</td>
</tr>
<tr>
<td>23</td>
<td>74</td>
<td>M</td>
<td>AMI</td>
<td>AF</td>
<td>O 1-00 (21 h)</td>
<td>—</td>
<td>12.5 (A fib)=25-50-100</td>
<td>NSR</td>
</tr>
<tr>
<td>24</td>
<td>48</td>
<td>M</td>
<td>CAD</td>
<td>VT</td>
<td>mD 0.25</td>
<td>—</td>
<td>1</td>
<td>NSR</td>
</tr>
<tr>
<td>25</td>
<td>57</td>
<td>M</td>
<td>CAD</td>
<td>VT</td>
<td>mD 0.25</td>
<td>L 200 (10 min)</td>
<td>12.5</td>
<td>NSR</td>
</tr>
<tr>
<td>26</td>
<td>67</td>
<td>M</td>
<td>CAD</td>
<td>VT</td>
<td>mD 0.125</td>
<td>—</td>
<td>12.5</td>
<td>NSR</td>
</tr>
<tr>
<td>1-10</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
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</tr>
</tbody>
</table>

A fib = atrial fibrillation; AF = atrial flutter; PAT = paroxysmal atrial tachycardia; VT = ventricular tachycardia; NSR = normal sinus rhythm; RHD = rheumatic heart disease; WPW = Wolff-Parkinson-White syndrome; CAD = coronary artery disease; AMI = acute myocardial infarction; D = digoxin; O = ouabain; m = daily maintenance dose; Dis = disopyramide; Pr = practolol; Q = quinidine; L = lignocaine.

Personnel and of drugs for immediate use should an emergency unexpectedly arise. The occurrence of ventricular arrhythmias after carotid sinus massage offers convenient clinical indicator of digitalis toxicity and is an important contraindication to cardioversion. However, cardioversion should not be withheld from patients on a correct dose of digitalis; in some circumstances this may be a life-saving procedure.

### References

- Hagemeijer, F., and Lown, B. (1970). Effect of heart rate on...
electrically induced repetitive ventricular responses in the digitalized dog. Circulation Research, 27, 333.


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