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# Initial Energy Setting, Outcome and Efficiency in Direct Current Cardioversion of Atrial Fibrillation and Flutter

Mark M. Gallagher, MD, Xiao-Hua Guo, MD, Jan D. Poloniecki, PHD, Yee Guan Yap, MB, David Ward, MD, A. John Camm, MD

*London, United Kingdom*

**OBJECTIVES** The purpose of this study was to design a more efficient protocol for the electrical cardioversion of atrial arrhythmias.

**BACKGROUND** Guidelines for electrical cardioversion of atrial arrhythmias recommend starting with low energy shocks, which are often ineffective.

**METHODS** We recorded the sequence of shocks in 1,838 attempts at cardioversion for atrial fibrillation (AF) and 678 attempts at cardioversion for atrial flutter. These data were used to calculate the probability of success for each shock of a standard series and the probability of success with a single shock at each intensity. In 150 cases, a rhythm strip with the time of each shock allowed us to calculate the time expended on unsuccessful shocks.

**RESULTS** We analyzed the effects of 5,152 shocks delivered to patients for AF and 1,238 shocks delivered to patients for atrial flutter. The probability of success on the first shock in AF of >30 days duration was 5.5% at <200 J, 35% at 200 J and 56% at 360 J. In atrial flutter, an initial 100 J shock worked in 68%. In AF of >30 days duration, shocks of <200 J had a 6.1% probability of success; this fell to 2.2% with a duration >180 days. In those with AF for >180 days, the initial use of a 360 J shock was associated with the eventual use of less electrical energy than with an initial shock of ≤100 J (581 ± 316 J vs. 758 ± 433 J, $p < 0.01$, Mann-Whitney *U* test).

**CONCLUSIONS** An initial energy setting of ≥360 J can achieve cardioversion of AF more efficiently in patients than traditional protocols, particularly with AF of longer duration. (J Am Coll Cardiol 2001;38:1498–504) © 2001 by the American College of Cardiology

Standard guidelines for transthoracic direct current (DC) cardioversion suggest starting with shocks of 50 to 100 J and progressing in steps to a maximum of 360 to 400 J (1,2). This approach was adopted because of fear that unnecessarily powerful shocks might damage the heart. Myocardial damage by DC shock has been demonstrated in animal models, but these studies involved shocks of far greater energy than those used in man (3–6). Biochemical studies suggest that no such damage occurs in clinical practice (7,8). It is recognized that the less powerful shocks often fail, but, in early series, the rate of success at low-energy settings was sufficient to justify their use (9).

Cardioversion is one of the most common procedures in cardiology. It is intensive of labor because it normally involves one physician who administers anesthesia and manages the airway while another administers the shock. Therefore, it is important to minimize the duration of the procedure and promote rapid recovery from the anesthetic. We have tried to determine whether efficiency could be improved by altering the traditional series of shocks of increasing energy.

From the Department of Cardiological Sciences, St. George's Hospital Medical School, London, United Kingdom. Supported by the British Heart Foundation Project Grant PG/96138.

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## METHODS

**Data collection.** In 13 hospitals, we identified patients who underwent DC cardioversion of atrial fibrillation (AF) or flutter between January 1, 1990 and June 30, 1997 and reviewed the hospital records of these patients. We identified the rhythm present immediately before cardioversion, the apparent duration of that arrhythmia, the schedule of shocks administered and the rhythm present after each shock.

Rhythm strips pertaining to 200 cardioversion attempts from one teaching hospital and one district hospital were inspected to verify the accuracy of rhythm interpretation and recording of shock. In 150 of these, the device used to deliver the shocks recorded the precise time of each shock on the rhythm strip, allowing us to calculate the interval between shocks.

A cardioversion attempt or an individual shock was designated as successful if sinus rhythm was restored for two or more beats. In a small number of cases, AF or flutter recurred after a brief period of sinus rhythm, and cardioversion was repeated immediately. In these, we analyzed only those shocks delivered before sinus rhythm was restored for the first time.

**Statistics.** Student *t* test was used to compare parametric variables. Comparison of nonparametric variables was by the Mann-Whitney *U* test. Nonparametric analysis of variance (Kruskal-Wallis test) and least-squares regression were used

**Abbreviations and Acronyms**
AF = atrial fibrillation
DC = direct current

to check for an association between the strength of the initial shock and total energy delivered. A life-table method was used to construct a model of cumulative success over a conventional sequence of shocks of increasing energy. This analysis was stratified for the duration of AF. For the series of shocks, we chose those steps for which we had data from more than 100 cardioversion attempts. This resulted in a sequence of one shock each at <50 J and 50 J followed by two shocks each at 100 J and 200 J and three shocks at 360 J. To avoid a bias in favor of higher energy shocks, initial shocks of >50 J and shocks that immediately followed a step-up in power greater than that in the above sequence were not used in constructing the life-table.

## RESULTS

In most cases AF or flutter was attributable to myocardial ischemia (19.6%), hypertension (15.9%), valvular heart disease (12.4%), excessive ethanol consumption (6.4%), heart failure or cardiomyopathy (9.0%). Lone AF was diagnosed in 21.1%.

The cardioversion attempts studied involved 6,390 DC shocks (Fig. 1), 5,152 shocks delivered during AF (2.8 ± 1.5 shocks per cardioversion attempt) and 1,238 shocks delivered during atrial flutter (1.8 ± 1.1 shocks per cardioversion attempt). Review of rhythm strips suggested that the rhythm was correctly identified in the vast majority of cases, with only one example of repeated shocks delivered in sinus rhythm in 200 cardioversion attempts.

**Success on first shock.** In many cases the procedure did not follow a standard protocol but was started with a shock of 200 J or 360 J (Fig. 2). This was used to determine the probability of success on the initial shock at each energy setting, in an analysis stratified in quartiles for AF duration. There was evidence that the physicians performing the cardioversion tailored the sequence of shocks to the patient. The initial shock intensity was greater in patients with AF of longer duration (Fig. 2) and in heavier patients. The probability of success on the first shock was related to the initial energy. In AF of >30 days duration, the rate of success with the initial shock was 5.5% at <200 J, 35% at 200 J and 56% at 360 J. With AF of <30 days duration, the probability of success at low power was 21% at 50 J and 31% at 100 J.

**Cumulative success.** The actual sequence of shocks was often different from the standardized protocol described in our life-table (Fig. 3). A failed shock at 100 J was followed by a second shock at 100 J in only 201 of 1,142 cases (17.6%). In 75.7% of the cases, the operator proceeded immediately to 200 J; in 5.3% there was a progression to 360 J, and in 1.5% the procedure was abandoned. Repetition without increase in power was less common after failures at 50 J (78/736, 10.6%) and more common after failure at 200 J (207/895, 23.1%).

There was a low rate of success with shocks of <200 J in AF of longer duration. Shocks of ≤50 J restored sinus rhythm in only 12/399 (3%) of cases where the duration was >30 days. At 100 J, 30 of 445 shocks were successful (6.7%) in this group compared with 215/834 (25.7%) of cases at 200 J and 413/1,136 (36.4%) of cases at 300 J to 360 J.

The probability of success at a given power setting was not predicted by the outcome of previous shocks. A patient with AF for >180 days with a failed shock at 200 J had a

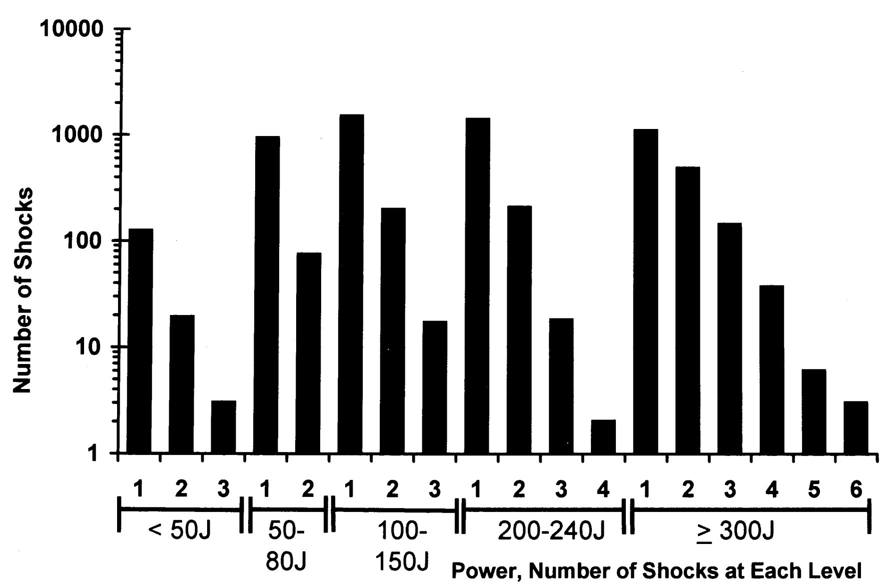


**Figure 1.** Characteristics of all 6,390 shocks analyzed. After each unsuccessful shock, the operator could abandon the procedure or progress to the next energy level. The procedure was frequently abandoned before reaching 360 J or after one or two shocks at this power.

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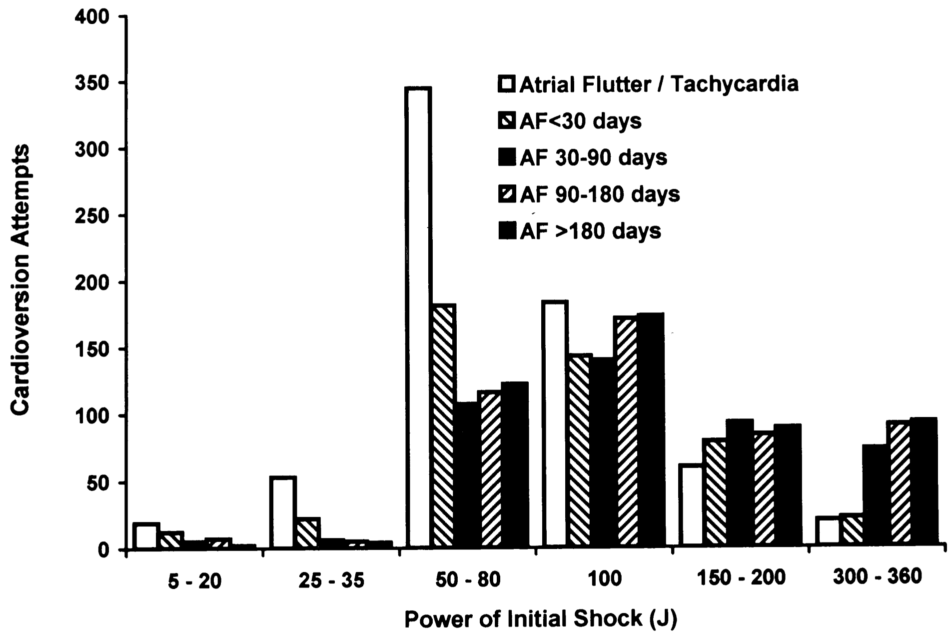


**Figure 2.** Starting energy used in 2,519 attempts at direct current cardioversion according to the rhythm converted and the duration of that arrhythmia. AF = atrial fibrillation.

28.9% probability of success with the first 360 J shock. A second 360 J shock succeeded in 56/191 (29.3%) of those in whom the first shock had failed, while a third shock succeeded in 18/59 (30.5%) of the remainder. In 53% of these cases, there was a change in shock vector from sternum-apex to anteroposterior or vice versa between the second and third shock at 360 J, but this did not appear to influence the outcome of the third shock.

Shocks that followed three or more failed shocks at the same energy setting had a chance of success, but there are fewer data on these steps. Success occurred on the fourth shock at 360 J in 10 of 37 attempts (27%), but there was no success in six cases of a fifth shock of 360 J.

The overall success rates predicted by our life-table differ from the observed reality (Table 1) because protocols of this type were seldom followed precisely. In most cases, the progression to high power occurred more rapidly, and the procedure was commonly abandoned prematurely (Fig. 4). In 114 of 447 failed cardioversion attempts (26%), the procedure was abandoned at <300 J, and, in a further 79 (18%) failed attempts, only one shock of ≥300 J was used. Only 84 failed attempts (19%) were associated with the use of three or more shocks of ≥300 J.

**Energy setting and number of shocks.** As expected, fewer shocks were needed if a higher initial energy was used (Fig. 5). The difference was more marked in those with AF for >180 days. In these cases, patients received 1.6 ± 0.9 shocks if the procedure started with a shock of 360 J

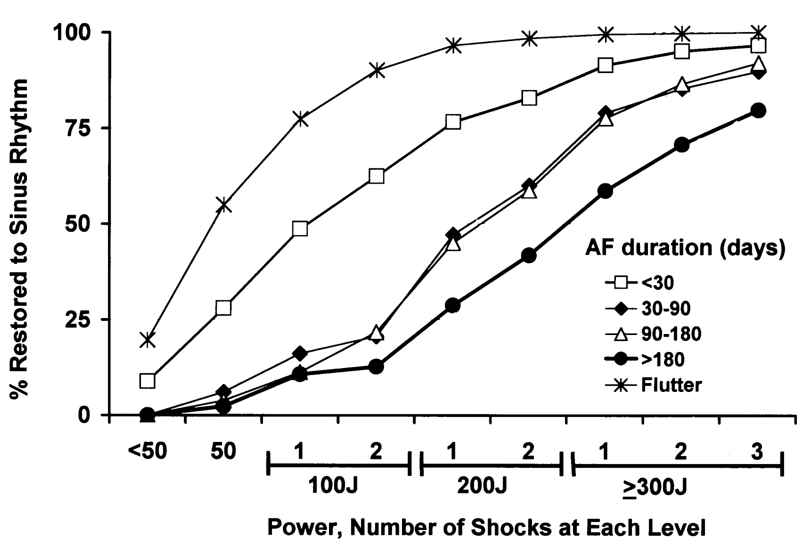


**Figure 3.** Model of cumulative success using a series of shocks of increasing intensity. AF = atrial fibrillation.

**Table 1.** The Predicted Success of a Series of Up to Nine Shocks Including Three at 360 J Was Not Matched in Clinical Practice*

| | Predicted Success (%) | Observed Success (%) |
|---|---|---|
| Atrial flutter | 100 | 96.8 |
| AF < 30 days | 96.5 | 83.7 |
| AF 30–90 days | 89.8 | 78.3 |
| AF 90–180 days | 92.0 | 77.4 |
| AF > 180 days | 79.7 | 65.8 |

*In practice, the procedure was commonly abandoned before reaching 360 J or after only one shock at this energy (Fig. 4).
AF = atrial fibrillation.

compared with 4.2 ± 1.4 shocks if the initial energy setting was 50 J ($p < 0.001$, Mann-Whitney *U* test). Our life-table suggests that the number of shocks per patient would have been even larger if standard protocols had been followed closely. With AF of >180 days duration, a median of 5.4 shocks per patient would be anticipated with this protocol.

There was a statistically significant association between the power of the initial shock and the total power delivered both for those with AF of <180 days ($p < 0.0005$) and >180 days duration ($p = 0.0053$) in nonparametric analysis of variance with the initial shock classified into three groups: ≤100 J, 101 J to 359 J, ≥360 J. In AF with a duration of <180 days, there was a positive correlation between the power of the first shock used and the total energy ($p = 0.02$, linear regression), while in those with AF for ≥180 days, the correlation was negative ($p = 0.0006$). The positive association between initial and total power is evident in Figure 6 in those with AF of ≤30 days duration. For patients with AF of 30 to 90 days duration, no association is evident, while for those with AF of >180 days duration, the association is reversed. In those with AF for ≥180 days, the total energy was significantly lower in those whose cardioversion began with a 360 J shock than it was in those who initially received ≤100 J (581 ± 316 J vs. 758 ± 433 J, $p < 0.01$, Mann-Whitney *U* test). The negative correlation between initial and total power for patients with AF for >180 days remained significant when the analysis was performed using only the first attempt at cardioversion for each patient ($n = 355$, $p = 0.01$, linear regression).

**Time management.** A rhythm strip bearing the time of delivery of each shock was available for 150 cardioversion attempts, of which 81 required more than one shock. The mean interval between shocks was 67 ± 50 s. The interval between first and second shock was 57 ± 46 s; the interval between subsequent shocks was significantly longer at 78 ± 52 s ($p < 0.01$, Student *t* test). In patients with AF for >180 days, the excess of 2.6 shocks per cardioversion attempt associated with a low initial energy setting would, therefore, involve an additional procedure time of >3 min.

## DISCUSSION

We have shown that an initial energy setting of ≥360 J can achieve cardioversion of AF more efficiently than traditional protocols, particularly when the duration of AF is longer. The saving of time is small, but, by reducing the duration of anesthesia, recovery of consciousness may also be accelerated. There is no indication that this high initial energy setting leads to an increase in adverse effects (10).

**Definition of success.** The overall rate of successful cardioversion in this series was high because of our limited technical definition of success. This definition of success as restoration of sinus rhythm for at least two beats is clearly not necessarily a clinically useful outcome. We chose this definition because it is important to distinguish between failure to restore sinus rhythm and failure to maintain that rhythm for long enough to provide a clinical benefit. If there is no interruption in the arrhythmia, the technique used for cardioversion was inadequate; if sinus rhythm is restored for only a short period, there is a need to address the continued predisposition to AF but no reason to alter the cardioversion procedure. We have reported a success rate far higher than

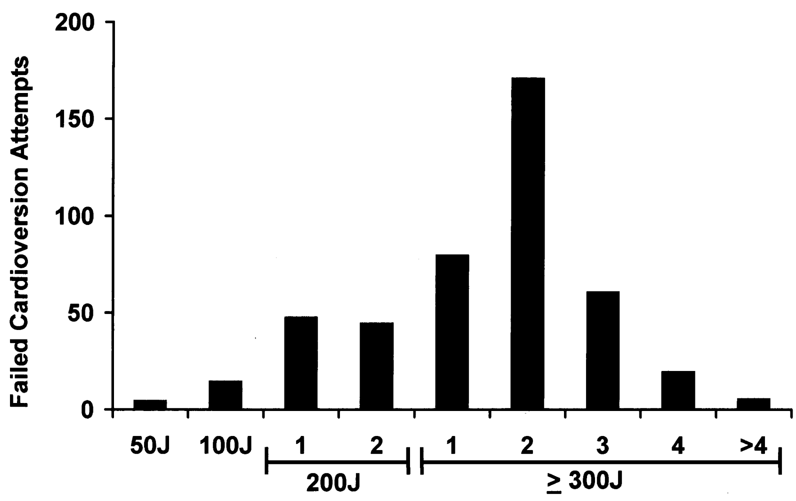


**Figure 4.** Analysis of the final shock in each of the 447 failed attempts at cardioversion. The procedure was commonly abandoned prematurely.

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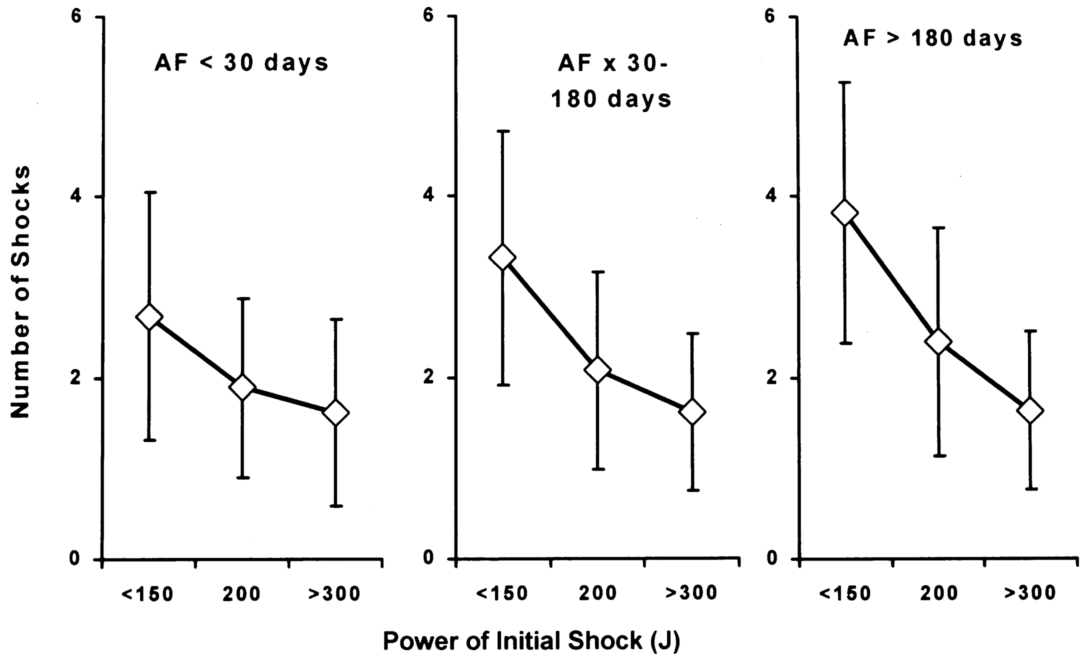


**Figure 5.** Number of shocks administered per cardioversion attempt. The number was greater in cases where the attempt started at low power, particularly in atrial fibrillation (AF) of longer duration.

those who defined success as the restoration of sinus rhythm for >24 h (11).

The rate of success at low-energy levels is lower in this series than in previous reports. One of the earliest reports quoted a 57% success rate at 100 J (9), and a recent series reported success at ≤100 J in 48% of cases (12). The discrepancy may reflect the greater size of our series or differences in patient characteristics, particularly the large number of patients with AF of long duration in our series. Because our series is retrospective, unselected and drawn from a number of hospitals, it probably reflects normal clinical practice more accurately than previous studies.

**Chronic AF.** Our data show that it is possible to achieve a high rate of cardioversion even in AF of >6 months duration. In practice, the success rate is far lower because of failure to use sufficient energy or failure to use a sufficient number of high-energy shocks. There is a substantial possibility of success even at the third or fourth shock at 360 J, and we cannot exclude an additional benefit if the shock vector is altered. The use of at least four shocks at

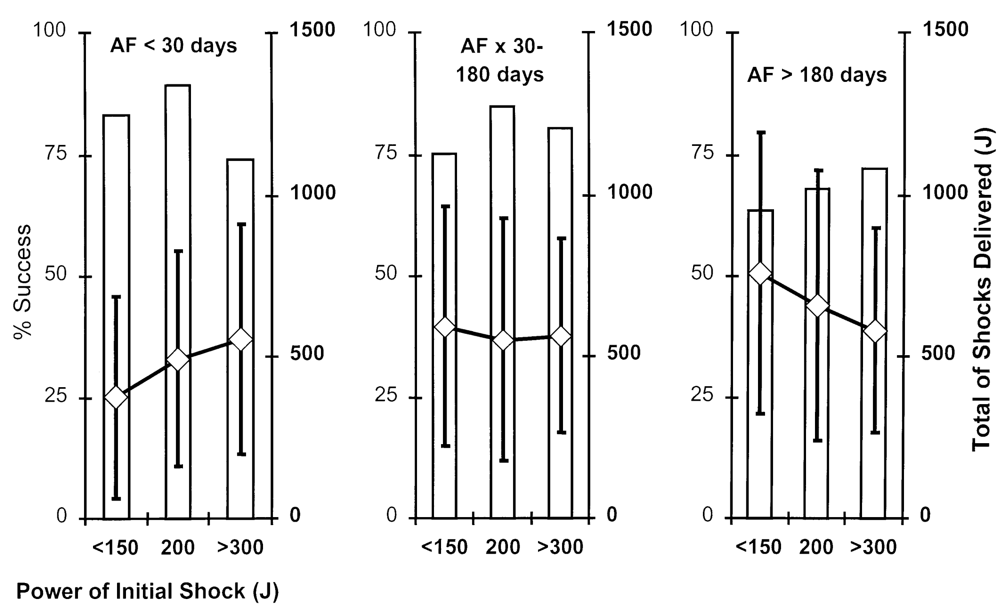


**Figure 6.** Relationship between initial energy setting and total energy delivered. In recent-onset atrial fibrillation (AF), starting at low energy reduces the total power administered. In AF of long duration, the initial use of 360 J is associated with the lowest total energy use and with a higher success rate.

360 J in at least two electrode configurations should be considered.

**The defibrillation threshold.** Successful cardioversion with the use of repeated shocks of a similar intensity can be explained by the probabilistic nature of the relationship between power and success (13). There is no single threshold above which success is certain or below which every shock will fail. The failure of a shock at a given power setting does not mean that the defibrillation threshold lies above that level, only that the probability of success at that setting is <100%.

Alterations in transthoracic impedance provide an alternative explanation for success of later shocks. It has been observed that, in animal models, DC shocks reduce transthoracic impedance. This could increase the proportion of the delivered energy that reaches the myocardium and might, thus, facilitate success on subsequent shocks (14). In human cardioversion, the effect of shocks on thoracic impedance appears to be small (15), so this is probably a minor factor.

**Cardioversion technique.** There is a large discrepancy between the potential success rate predicted by our model and the observed success rate. This emphasizes the importance of careful technique. Our data suggest that, in practice, failure is often due to premature abandonment of the procedure. Others have shown that electrode position is important (16) and that increased pressure on the electrodes improves the probability of cardioversion (17). Concurrent use of antiarrhtythmic drugs (18), the use of energy levels higher than those in routine use at present (19), the use of appropriate electrode polarity (20) or of an alternative shock waveform (21) might improve success rates further. These approaches should improve the overall efficacy of transthoracic cardioversion, reducing the number of patients exposed to the hazards of internal cardioversion (22) or condemned to a lifetime of AF.

**Study limitations.** These data were collected retrospectively, and the choice of electrical energy used was dictated by physician preference. There was evidence of a tendency for physicians to start at higher energy in those patients likely to prove difficult to cardiovert. Therefore, we have relatively little data on the effects of more powerful shocks in AF of recent onset or the effects of very weak shocks in AF of long duration.

**Conclusions.** In persons who have had AF for <30 days, sinus rhythm can often be restored by shocks of 100 J, and conventional protocols are efficient. With AF of longer duration, success is very unusual at <200 J. Therefore, a starting power of ≥200 J is appropriate. In heavier patients or those with AF for >180 days, an initial setting of ≥300 J is appropriate. This energy level appears safe and should also be considered in AF of 30 to 180 days duration. Cardioversion of atrial flutter seldom requires >200 J, and a starting power of 100 J is efficient. Success may occur on the third or subsequent attempt at an intensity that initially proves unsuccessful.

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**Reprint requests and correspondence:** Dr. Mark M. Gallagher, Department of Cardiological Sciences, St. George's Hospital Medical School, Cranmer Terrace, London SW17 ORE, United Kingdom. E-mail: mm.gallagher@virgin.net.

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