Higher Energy Synchronized External Direct Current Cardioversion for Refractory Atrial Fibrillation

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OBJECTIVES
We sought to evaluate the safety and efficacy of higher energy synchronized cardioversion in patients with atrial fibrillation refractory to standard energy direct current (DC) cardioversion.

BACKGROUND
Standard external electrical cardioversion fails to restore sinus rhythm in 5% to 30% of patients with atrial fibrillation.

METHODS
Patients with atrial fibrillation who failed to achieve sinus rhythm after at least two attempts at standard external cardioversion with 360 J were included in the study. Two external defibrillators, each connected to its own pair of R-2 patches in the anteroposterior position, were used to deliver a synchronized total of 720 J.

RESULTS
Fifty-five patients underwent cardioversion with 720 J. Mean weight was 117 ± 23 kg (body mass index 48.3 ± 4.1 kg/m²). Structural heart disease was present in 76% of patients. Mean left ventricular ejection fraction was 45 ± 12%. Atrial fibrillation was present for over three months in 55% of the patients. Sinus rhythm was achieved in 46 (84%) of the 55 patients. No major complications were observed. No patient developed hemodynamic compromise and no documented cerebrovascular accident occurred within one month after cardioversion. Of the 46 successful cardioversions, 18 patients (39%) remained in sinus rhythm over a mean follow-up of 2.1 months.

CONCLUSIONS
External higher energy cardioversion is effective in restoring sinus rhythm in patients with atrial fibrillation refractory to standard energy DC cardioversion. This method is safe and does not result in clinical evidence of myocardial impairment. It may be a useful alternative to internal cardioversion because it could be done within the same setting of the failed standard cardioversion and obviates the need to withhold protective anticoagulation for internal cardioversion. (J Am Coll Cardiol 1999;34:2031–4) © 1999 by the American College of Cardiology

Direct current (DC) cardioversion, first reported by Lown et al. (1), remains the most effective approach to convert atrial fibrillation to sinus rhythm. However, external cardioversion using currently available maximal energies is ineffective for 5% to 30% of patients (2–4). Multiple factors contribute to failure, including duration of atrial fibrillation, position and size of shock electrodes (5) and patient body habitus, which influences transthoracic impedance (6). High impedance can decrease the effective energy delivered to the atria in large-bodied patients. Patients in whom standard external cardioversion fails often receive treatment aimed at rate control alone or an attempt at internal cardioversion (4). Although internal cardioversion has been effective when atrial fibrillation is refractory to external cardioversion, it requires invasive placement of right atrial, coronary sinus or pulmonary artery defibrillation electrodes. This can be problematic because of the need for periprocedural discontinuation of anticoagulation. Such discontinuation may increase the risk of left atrial clot formation and systemic embolization.

We report a novel method of delivering synchronized, higher energy DC external shocks for cardioversion of atrial fibrillation refractory to conventional external cardioversion energies. This method has essentially eliminated the need for invasive internal cardioversion at our institution.

METHODS
Patients undergoing routine cardioversion of atrial fibrillation in our electrophysiology laboratory were included in this report if they did not achieve any beats of sinus rhythm...
after standard external DC cardioversion with maximal energies of 360 J in the anteroposterior patch positions. Repeat cardioversion with 360 J was attempted before proceeding to the high energy cardioversion protocol. In all patients, therefore, cardioversion of atrial fibrillation failed with at least two attempts at 360 J using our standard approach.

Written, informed consent was obtained from all patients before the procedures. Two external defibrillators (PD 1200, Zoll Medical Corp., Woburn, Massachusetts) were each connected to a separate pair of R-2 patches (Stat-padz, Zoll Medical Corp., Burlington, Massachusetts). Each pair of patches was placed in the anteroposterior position of the patient’s chest. The two anterior patches were placed next to each other. Similarly, the two posterior patches were placed adjacent to each other. A five-electrode electrocardiographic (ECG) signal was split using a custom-made signal splitter (ECG) signal was split using a custom-made signal splitter that were used for rate control in 63%, 20% and 38% of the patients, respectively.

Statistical analysis. Results are reported as the mean ± SD with 95% confidence limits, unless reported otherwise.

RESULTS

Between June 1996 and April 1999, 55 patients underwent cardioversion with 720-J shocks. Patient characteristics are summarized in Table 1. The mean left ventricular ejection fraction was 45 ± 12%, as estimated by echocardiography or radionuclide ventriculography. The left atrium was normal in 10 patients (18.1%), mildly enlarged in 22 (40.1%), moderately enlarged in 12 (21.8%) and severely enlarged in 2 (3.6%). Nine patients did not have left atrial dimensions available. Thirteen patients (23.6%) did not have evidence of structural heart disease. Coronary artery disease was present in 12 (21.8%), left ventricular hypertrophy in 13 (23.6%), valvular heart disease in 7 (12.7%) and primary myocardial disease (dilated cardiomyopathy, right ventricular dysfunction) in 12 (21.8%) patients.

Atrial fibrillation was present for >1 year before the cardioversion in 12 (22%), three months to one year in 18 (33%), one month to three months in 13 (24%) and <1 month in 10 (18%) patients. In two patients, the duration could not be ascertained. All patients were anticoagulated. Ninety percent were on Coumadin (warfarin sodium) with an international normalized ratio (INR) ≥2; 10% were on heparin because of new-onset atrial fibrillation or inadequate anticoagulation with Coumadin.

Fourty-eight patients (87%) were taking antiarrhythmic medication at the time of cardioversion. Antiarrhythmic medications included amiodarone (41%), sotalol (20%), flecainide (20%), procainamide (4%) and disopyramide (2%). Digoxin, calcium channel blockers and beta-blockers were used for rate control in 63%, 20% and 38% of the patients, respectively.

Eleven patients received more than one attempted 720-J shock at the same session—in eight patients because the 720-J shocks failed to terminate atrial fibrillation and in one patient because of recurrence of atrial fibrillation within 5 min of the initial 720-J shock. In two patients a repeat attempt was performed because the initial attempt triggered only one of the two defibrillators. This failure to trigger both defibrillators was due to inadequate application of simultaneous manual pressure on the two defibrillator switches.

Sinus rhythm was achieved in 46 (84%) of the 55 patients (95% confidence interval 74% to 93%). Chart review or telephone follow-up was adequate in 53 of the 55 patients to determine whether there was recurrence of atrial fibrillation. Of the 46 patients with successful cardioversion, atrial fibrillation recurred in 28 (61%). Recurrence was within 24 h in 8 patients, 1 to 30 days in 13 patients, 30 to 90 days in 4 patients and >90 days in 1 patient. Eighteen patients (39%) remained in sinus rhythm during a mean follow-up period of 2.1 ± 1.8 months. One patient with successful cardioversion was lost to follow-up. Of the 28 patients with recurrent atrial fibrillation, four patients underwent a second cardioversion and three patients underwent two further cardioversions using the 720-J shock at a later date, all of which were successful in achieving sinus rhythm.

No patient developed hemodynamic compromise or congestive heart failure. One patient developed transient bradycardia without sequelae. In another patient (taking amiodarone) cardioversion failed and transient right bundle branch block (RBBB) developed, and, later that day, she

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**Abbreviations and Acronyms**

- DC = direct current
- ECG = electrocardiogram
- RBBB = right bundle branch block
developed sinus bradycardia–induced torsade de pointes. She underwent pacemaker placement and the remainder of her hospital course was uneventful. Interestingly, she weighed 71 kg and was the lightest of the patients included in this report. There was no documented stroke or transient ischemic cerebral event reported within one month after cardioversion. No patient had any recollection of receiving a shock during cardioversion or reported any undue pain or discomfort related to the procedure. Skin injury was limited to the usual irritation around the patches observed after cardioversion with our standard approaches.

**DISCUSSION**

Our study shows that higher energy cardioversion is an effective and safe option to restore sinus rhythm in patients refractory to standard energy external cardioversion. Our success rate, 84% conversion of atrial fibrillation, was similar to those of previous preliminary reports (7,8).

**Potential for myocardial damage.** It has been reported that excessive energy delivery with cardioversion attempts can induce myocardial damage (9), manifested as gross and histologic abnormalities along with elevation of serum cardiac enzymes. Most of the reports in the published data that showed significant myocardial damage were done in open-chest animals and used shocks delivered in sinus rhythm. It has been postulated that the mechanism of such damage is mediated through generation of free radicals, which are toxic to the myocardium (10), and is related to the shock energy used. Other studies suggested that the total electrical energy used for cardioversion does not affect the degree of mechanical dysfunction of either the left atrium or the left atrial appendage after conversion to sinus rhythm (11). In the present study, cardiac enzymes were not routinely obtained after the procedure. However, other investigators have reported no significant increase in creatine kinase, MB fraction after cardioversion with 720-J shocks. (8) In our study, none of the patients developed significant hemodynamic compromise or high grade atrioventricular block after the procedure.

**Selection of patients.** In all our patients cardioversion failed at maximal energies available with a standard external defibrillator. The efficacy of defibrillation is in part related to transthoracic impedance (6). Increased transthoracic impedance is related to body habitus. Thus, large patients may require the application of a higher level of external energy to achieve an adequate but not excessive amount of cardiac current flow for effective cardioversion. Given the size of our patients, as shown by the mean body mass index (Table 1), failure of standard energy cardioversion was most likely due to increased transthoracic impedance, resulting in insufficient current reaching the myocardium.

**Comparison to internal cardioversion.** Internal cardioversion has been effective in restoring sinus rhythm in 71% to 91% of patients with atrial fibrillation refractory to external cardioversion (4, 12, 13). However, internal cardioversion requires invasive catheterization for placement of right atrial, coronary sinus or pulmonary artery defibrillation electrodes. This may be problematic because of the need to stop or reduce anticoagulation around the time of the procedure, potentially increasing the risk of embolic stroke. Attempting higher energy external cardioversion first seems justifiable in view of the similar efficacy and the absence of clinical complications in our study.

**Mechanism of improved cardioversion.** It is interesting to speculate on the potential mechanism by which the use of two defibrillators, as reported here, could improve defibrillation success. In our setup, the defibrillation system capacitance is doubled, whereas the peak voltage of each defibrillator is the same. The use of two sets of skin electrodes doubles the surface area of the electrodes and reduces overall transthoracic impedance. We did not measure this impedance and thus could not quantify this decrease. Although the peak voltage delivered by the defibrillators does not increase, it is likely that voltage gradients in portions of the heart increase due to the greater current delivery in this setup. Lack of success in large patients using a single defibrillator is likely due to a low voltage gradient in at least some portions of the atria. The use of two sets of patches may improve the voltage gradients in those areas owing to the position of the second set of patches increasing the spread of the shock field in combination with the increased current flow.

**Potential problems.** The one patient who developed transient RBBB was the lightest in weight of our patient group. Thus, we would advocate caution in applying this technique to patients of normal or light weight, as the additional delivered energy may have a greater propensity to cause harm in such patients. The potential for damage to the defibrillators should also be considered. In our study, the defibrillator skin electrodes were not in contact with each other. However, if the electrodes were to touch each other and provide a low impedance path for current to flow from one defibrillator to another, there is some potential for causing harm to the defibrillators if the defibrillators did not synchronize appropriately. In our patient group, we did not observe any harm to the defibrillators, as evidenced by the continued normal operation of the defibrillators at subsequent use and testing.

**Future directions.** External defibrillators with biphasic waveforms are becoming available for clinical use. The biphasic waveform has been reported to be more effective than the monophasic waveform for cardioverting ventricular tachyarrhythmias (14–16). Thus, it would be reasonable to hypothesize that biphasic waveforms may be more efficacious in external cardioversion of atrial fibrillation as well. The energy requirement necessary with a biphasic waveform remains to be determined.
Study limitations and conclusions. Higher energy synchronized external DC cardioversion of atrial fibrillation was an effective and safe method for restoring sinus rhythm in our patients who were refractory to standard energy attempts. Because our group included predominantly patients of large body habitus, this procedure can only be recommended in patients with similar body weights in whom conventional external cardioversion has failed. Caution must be used in smaller patients in whom cardioversion has failed. Failure in these cases may not be related to inadequate cardiac current flow, and the risk of myocardial injury may be greater.

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REFERENCES