Low-Energy Cardioversion With Epicardial Wire Electrodes: New Treatment of Atrial Fibrillation After Open Heart Surgery

Andreas Liebold, MD; Alexander Wahba, MD; Dietrich E. Birnbaum, MD

Background—Atrial fibrillation (AF) is the most common arrhythmia after open heart surgery. Traditional treatment with a range of antiarrhythmic drugs and electrical cardioversion is associated with considerable side effects. The aim of this study was to examine the feasibility and efficacy of low-energy atrial defibrillation with temporary epicardial defibrillation wire electrodes.

Methods and Results—Epicardial defibrillation wire electrodes were placed at the left and right atria during open heart surgery in 100 consecutive patients (age 65 ± 9 years; male to female ratio 67:23). Electrophysiological studies performed postoperatively revealed a test shock (0.3 J) impedance of 96 ± 12 Ω (monophasic) and 97 ± 13 Ω (biphasic). During their hospital stay, AF occurred in 23 patients (23%) at 2.1 ± 1.3 days postoperatively. Internal atrial defibrillation was performed in 20 patients. Of these patients, 80% (16/20) were successfully cardioverted with a mean energy of 5.2 ± 3 J. Early recurrence of AF (<60 seconds after defibrillation) developed in 8 patients. Five patients had multiple episodes of AF. In total, 35 episodes of AF were treated, with an 88% success rate. Only 6 patients (30%) required sedation. No complications were observed with shock application or with lead extraction.

Conclusions—Atrial defibrillation with temporary epicardial wire electrodes can be performed safely and effectively in patients after cardiac operations. The shock energy required to restore sinus rhythm is low. Thus, patients can be cardioverted without anesthesia. (Circulation. 1998;98:883-886.)

Key Words: defibrillation ■ electrical stimulation ■ atrium ■ cardioversion

Atrial tachyarrhythmias constitute the most common arrhythmia after open heart surgery. The incidence varies between 26% and 41%.[1,6] In recent years, the reported incidence has increased.[2,5] Atrial fibrillation (AF) has been associated with a high incidence of postoperative strokes, ventricular arrhythmias, hemodynamic deterioration, and the need for a permanent pacemaker.[3,5]

Numerous studies of perioperative pharmacological prophylaxis of atrial tachyarrhythmias after open heart surgery have been published.[7–9] However, prophylactic treatment either failed to significantly reduce the incidence of AF or had considerable side effects. Established treatment of AF consists of the administration of a variety of antiarrhythmics. Electrical transthoracic cardioversion under general anesthesia is performed when AF results in hemodynamic instability.

A new method of internal electrical cardioversion that uses epicardial wire electrodes with low shock energies was developed in a canine model.[10,11] Clinical trials confirmed that low-energy atrial defibrillation via endocardial electrodes placed in the coronary sinus and the right atrial appendage is possible in humans.[12,13]
Patients contained a 5-mm ring electrode that allowed bipolar sensing and pacing (pacing electrode). The tip was connected to a needle for direct suture to the epicardium with 5 to 6 intramural stitches. The right atrial electrode was implanted encircling an area of the free right atrial wall between superior and inferior venae cavae, and the left atrial electrode was secured encircling the space between the AV groove and the left upper and lower pulmonary veins. Thus, the bulk of the atrial muscle mass was located between the 2 circles of the wire electrodes (Figure 1). A third epicardial electrode for temporary use (TME 63-Z; Sulzer-Osypka Inc) was sutured to the anterior wall of the right ventricle to ensure R-wave synchronization of atrial cardioversion. The electrodes were brought out through the skin and secured with a suture.

On arrival in the intensive care unit, the pacing threshold and impedance, as well as P- and R-wave amplitudes, were measured with a pacing system analyzer (ERA 20; Biotronik GmbH). Bifascial monophasic and biphasic test shocks of 0.3 J were delivered, and the threshold was 2.1 ± 0.6 V in the right atrium and 1.9 ± 0.7 V in the left atrium. Right and left atrial P-wave amplitudes were 2.3 ± 1.4 and 2.5 ± 1.6 mV, respectively. The mean biatrial lead impedance was 95.5 ± 12 Ω for monophasic test shocks and 97.2 ± 13 Ω for biphasic test shocks.

Of the 100 patients studied, 23 (23%) developed AF during their postoperative course. The onset of AF occurred at a mean of 2.1 ± 1.3 days postoperatively. Two patients had self-limiting episodes of AF that converted to SR spontaneously before electrical cardioversion. Another case of AF was treated medically because the patient removed the defibrillation wires himself in a state of temporary neurological impairment.

The remaining 20 patients were treated by internal atrial defibrillation. In 16 patients (80%), AF was successfully converted to SR with a mean shock energy of 5.2 ± 3 J. ERAF occurred in 8 patients. Four patients converted to SR within 48 hours of receiving antiarrhythmic medication. The other 4 patients with ERAF were successfully cardioverted with a mean shock energy of 9.1 ± 3 J after 48 hours of receiving antiarrhythmic medication. Five patients experienced multiple episodes of AF (2 experienced 2 episodes; 1 experienced 3 episodes; and 1 experienced 6 episodes). LRAF was terminated by single shocks with the same energy as the first successful shock in all patients. The interval between multiple episodes of LRAF ranged from 16 hours to 7 days. The latest onset of an LRAF episode occurred in a 76-year-old patient 17 days after aortic valve replacement. She was cardioverted with a 6-J shock and maintained SR until hospital discharge.

**Table: Patient Characteristics**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients</td>
<td>100</td>
</tr>
<tr>
<td>Male/female</td>
<td>77/23</td>
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<tr>
<td>Age, y</td>
<td>64.6 ± 9 (37–84)</td>
</tr>
<tr>
<td>NYHA class, n</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>1</td>
</tr>
<tr>
<td>II</td>
<td>46</td>
</tr>
<tr>
<td>III</td>
<td>42</td>
</tr>
<tr>
<td>IV</td>
<td>11</td>
</tr>
<tr>
<td>History of AF, %</td>
<td>6</td>
</tr>
<tr>
<td>History of CHF, %</td>
<td>18</td>
</tr>
<tr>
<td>History of MI, %</td>
<td>36</td>
</tr>
<tr>
<td>LVEF, %</td>
<td>61 ± 18 (14–90)</td>
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<td>β-Blockers preoperatively, %</td>
<td>57</td>
</tr>
<tr>
<td>Digoxin preoperatively, %</td>
<td>14</td>
</tr>
</tbody>
</table>

NYHA indicates New York Heart Association functional class; AF, preoperative intermittent atrial fibrillation; CHF, congestive heart failure; MI, myocardial infarction; and LVEF, left ventricular ejection fraction.

Placement of the epicardial defibrillation electrodes added 3.9 ± 1.7 minutes to the operating time. The mean pacing threshold was 2.1 ± 0.2 V in the right atrium and 1.9 ± 1.7 V in the left atrium. Right and left atrial P-wave amplitudes were 2.3 ± 1.4 and 2.5 ± 1.6 mV, respectively. The mean biatrial lead impedance was 95.5 ± 12 Ω for monophasic test shocks and 97.2 ± 13 Ω for biphasic test shocks.

No prophylactic antiarrhythmic drugs were administered.

In the event of AF, patients were immediately connected to an external defibrillator (Life Pak 10; Physio Control Corp) via a defibrillation interface module (InControl Inc) to apply R-wave synchronous monophasic shocks with very low energies (0.6 to 10.8 J). The first shock delivered to every treated patient had an energy of 2 J. If unsuccessful, the shock energy was increased stepwise (from 3 to 4 to 6 J) up to 10.8 J. If multiple shocks were applied in an awake patients, sedatives (midazolam 2 to 5 mg IV) and analgesics (pirotiram 2 to 5 mg IV) were given on patient request.

The treatment was termed primarily successful if AF was successfully converted to SR (Figure 2). Early recurrent AF (ERAF) was defined as recurrence of AF within 60 seconds of successful cardioversion. In the case of ERAF, patients were medically treated depending on their preoperative medication. If patients were receiving β-blockers, AF was treated with sotalol; otherwise, it was treated with verapamil. If AF persisted ≥48 hours, a second attempt of internal defibrillation was made. Late recurrent episodes of AF (LRAF) were also treated by means of atrial defibrillation.

Before hospital discharge, the wire electrodes were removed by simple transcutaneous retraction. After extraction, the wires were checked for completeness. For patients who underwent surgery for valve replacement, anticoagulation with warfarin was started on postoperative day 3. The extraction technique and timing were the same for all patients regardless of anticoagulation therapy.

Data are presented as mean ± SD.

**Results**

Two patients had self-limiting episodes of AF that converted to SR spontaneously before electrical cardioversion. Another case of AF was treated medically because the patient removed the defibrillation wires himself in a state of temporary neurological impairment.

The remaining 20 patients were treated by internal atrial defibrillation. In 16 patients (80%), AF was successfully converted to SR with a mean shock energy of 5.2 ± 3 J.

ERAF occurred in 8 patients. Four patients converted to SR within 48 hours of receiving antiarrhythmic medication. The other 4 patients with ERAF were successfully cardioverted with a mean shock energy of 9.1 ± 3 J after 48 hours of receiving antiarrhythmic medication. Five patients experienced multiple episodes of AF (2 experienced 2 episodes; 1 experienced 3 episodes; and 1 experienced 6 episodes). LRAF was terminated by single shocks with the same energy as the first successful shock in all patients. The interval between multiple episodes of LRAF ranged from 16 hours to 7 days. The latest onset of an LRAF episode occurred in a 76-year-old patient 17 days after aortic valve replacement. She was cardioverted with a 6-J shock and maintained SR until hospital discharge.

**Figure 1.** Two views of human heart showing epicardial defibrillation wire electrodes in place. Distal 10 cm of wire electrodes is represented by an interrupted line forming an O-shaped surface area at right and left atria, respectively. SVC indicates superior vena cava; IVC, inferior vena cava; RAA, right atrial appendage; Ao, Aorta; PA, pulmonary artery; PV, pulmonary veins; and CS, coronary sinus.
In total, 35 episodes of spontaneous AF were treated by internal atrial defibrillation, with a success rate of 88% (31/35).

Most cardioversions was performed in the cardiac surgical ward without anesthesia. Only 6 of the 20 electrically treated patients (30%) required sedation or analgesia. No general anesthesia was used.

The wires were removed at a mean interval of 5.7±1.9 days postoperatively by simple transcutaneous traction. No patient left the hospital with the wires in place. No complications related to the extraction of the wires (in particular, no bleeding) were observed.

**Discussion**

Although AF after open heart surgery generally carries a favorable prognosis, hemodynamic deterioration and systemic embolization may ensue. Hemodynamic instability is more common in patients with poor left ventricular function (ejection fraction <30%), in whom postoperative AF is more likely to occur.2,5

Cerebrovascular accidents after open heart surgery are more common in patients with AF.3,14,15 Creswell et al1 reported that postoperative AF increased the risk of postoperative stroke from 1.4% to 3.3% (P<0.0005). Others found a significantly higher combined incidence of stroke and transient ischemic attacks in patients with AF after CABG (60% versus 18%, respectively; P<0.0005).15 Moreover, the development of AF after open heart surgery prolongs the hospital stay and increases the costs of treatment.2,3,5,15,16

Knowledge of the pathophysiology of AF after open heart surgery is incomplete. Thus, antiarrhythmic medication aimed at slowing the ventricular rate with a variety of drugs, including digitalis, β-blockers, and calcium channel antagonists, is usually prescribed. Other antiarrhythmics such as quinidine, propafenone, procainamide, disopyramide, amiodarone, and sotalol are frequently used to restore SR. These drugs, however, carry the risk of potentially serious side effects. Quinidine, the antiarrhythmic most commonly used to treat AF, has been shown to lead to a 3-fold increase in unadjusted mortality rate of treated patients compared with control subjects.17

Usually, transthoracic cardioversion is only used when SR cannot be restored by other means or when control of the ventricular rate is insufficient.

The feasibility of internal electrical cardioversion of atrial tachycardias has been shown in animal18,19 and clinical studies.12,13,21 Using a canine sterile pericarditis model, Ortiz et al11 demonstrated that atrial defibrillation could be accomplished by low-energy shocks delivered through epicardial wire electrodes.

Temporary pacing leads are routinely used after open heart surgery. The electrical properties of the wire electrodes used in the present study included both bipolar atrial sensing and pacing, as well as biatrial defibrillation. Adequate sensing and secure pacing were achieved in both atria. The mean lead impedance during test shock application with this system was significantly higher than that reported by Schmitt et al21 using transvenous leads in 25 patients after failed transthoracic cardioversion. These findings correspond to the results of Ortiz et al,11 who compared epicardial wire electrodes with transvenous electrodes in dogs. The higher impedance of epicardial electrodes probably reflects the inclusion of more atrial musculature within the electrical field between the electrodes. In contrast to Cmolik et al10 and Ortiz et al,11 who used a straight lead configuration, we placed the electrodes uniformly in an O-shaped manner. The straight configuration bears the risk of lead dislodgement and consecutive loss of capture. Furthermore, we intended to use all 10 cm of the defibrillation electrode to obtain the maximal shock impedance. From an electrical point of view, the O-shaped configuration should be preferred because higher shock impedance means less shock energy. Although our method is more time-consuming, we felt comfortable with a stable position and optimal electrical values.

The primary goal of this study was to investigate the safety and efficacy of epicardial cardioversion in patients after cardiac surgery. We demonstrated a primary success rate of 80% and an overall success rate of 88% with energy as low as 5.2±3 J. Because this is the first study in humans that used epicardial defibrillation electrodes to treat postoperative AF, no data are available in the literature to compare the energy required for successful cardioversion. In transvenous cardioversion of chronic AF,12,20 similar energies were used to restore SR. In the present study, most patients (70%) did not request sedation or analgesia.

A high incidence of ERAF was an important observation in the present study. We cannot determine whether concomitant antiarrhythmic medication is helpful in maintaining SR after
electrical cardioversion on the basis of our data. Further studies are required to clarify this issue.

We conclude that atrial defibrillation with temporary epicardial wire electrodes can be performed effectively without anesthesia in patients after open heart surgery. Easy placement and uncomplicated removal of the wires, as well as a quick and safe atrial shock application, are advantages of the system we used. Because the shock intensity needed to defibrillate the atria is low, cardioversion is well tolerated by patients and can be performed in the ward. Thus, internal atrial defibrillation is a valuable tool in patients with AF after open heart surgery.

References


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