Atrial Defibrillation With a Transvenous Lead
A Randomized Comparison of Active Can Shocking Pathways
Michael Cooklin, MRCP, MD, Mary R. Olsovsky, MD, Randall G. Brockman, MD, Stephen R. Shorofsky, MD, PhD, FACC, Michael R. Gold, MD, PhD, FACC
Baltimore, Maryland

OBJECTIVES
The purpose of this study was to compare transvenous atrial defibrillation thresholds with lead configurations consisting of an active left pectoral electrode and either single or dual transvenous coils.

BACKGROUND
Low atrial defibrillation thresholds are achieved using complex lead systems including coils in the coronary sinus. However, the efficacy of more simple ventricular defibrillation leads with active pectoral pulse generators to defibrillate atrial fibrillation (AF) is unknown.

METHODS
This study was a prospective, randomized assessment of shock configuration on atrial defibrillation thresholds in 32 patients. The lead system was a dual coil Endotak DSP lead with a left pectoral pulse generator emulator. Shocks were delivered either between the right ventricular coil and an active can in common with the proximal atrial coil (triad) or between the atrial coil and active can (transatrial).

RESULTS
Delivered energy at defibrillation threshold was 7.1 ± 6.0 J in the transatrial configuration and 4.0 ± 4.2 J in the triad configuration (p < 0.005). Moreover, a low threshold (≤3 J) was observed in 69% of subjects in the triad configuration but only 47% in the transatrial configuration. Peak voltage and shock impedance were also lowered significantly in the triad configuration. Left atrial size was the only clinical predictor of the defibrillation threshold (r = 0.57, p < 0.002).

CONCLUSIONS
These results indicate that low atrial defibrillation thresholds can be achieved using a single-pass transvenous ventricular defibrillation lead with a conventional ventricular defibrillation pathway. These data support the development of the combined atrial and ventricular defibrillator system. (J Am Coll Cardiol 1999;34:358–62) © 1999 by the American College of Cardiology

The implantable cardioverter defibrillator (ICD) is now primary therapy for many patients with life-threatening ventricular arrhythmias (1–3). Clinically significant atrial fibrillation (AF) is frequently observed in patients with ICDs; indirect data suggest an incidence of at least 20%, although the exact figure is unknown and may be higher (4). The presence of AF in general is associated with an increased incidence of thromboembolic events including stroke, adverse effects on cardiac function and increased mortality (5–7). In addition, many patients are severely symptomatic even if the AF is not hemodynamically compromising (8).

An implantable atrial defibrillator is currently undergoing clinical evaluation (9). On the basis of experimental and clinical studies, low atrial defibrillation thresholds have been demonstrated using complex lead systems including coils in the coronary sinus (10–12). Given the high incidence of AF in patients with ICDs, the possibility of using these devices for atrial defibrillation is intriguing. Because standard active pectoral ICD lead systems deliver current with a vector through the heart including the atria, we postulated that an active pectoral, single-pass lead would be an effective means to achieve atrial defibrillation, and further, that the efficacy of this system would be dependent on the shocking pathway. Accordingly, the present study was a prospective randomized evaluation of active can lead configuration on atrial defibrillation thresholds in patients undergoing ICD implantation. In addition to measuring the efficacy of atrial defibrillation, the clinical predictors of a low defibrillation threshold were assessed.

METHODS
Patient group. Thirty-four consecutive patients undergoing initial ICD implant for standard indications were evaluated. By protocol, all patients were in sinus rhythm at the time of implant, and all implants were left-sided. Written informed consent was obtained from each patient,
Transvenous Atrial Defibrillation

Cooklin et al. 359

JACC Vol. 34, No. 2, 1999
August 1999:358–62

Abbreviations and Acronyms
AF = atrial fibrillation
ICD = implantable cardioverter defibrillator

and the study was approved by the Institutional Review Board of the University of Maryland.

Defibrillation lead system implantation. Each patient received an Endotak DSP defibrillation lead (Model 0125), which was positioned at the right ventricular apex under fluoroscopic guidance via either the left cephalic, axillary or subclavian vein. This lead consists of two defibrillating coils, a proximal coil at the right atrial/superior vena cava junction and a second distal coil in the right ventricle. In patients undergoing dual-chamber ICD implant, a separate active fixation atrial lead (Model 4269) was placed in the right atrium. In the remaining patients, a temporary quadripolar pacing catheter was advanced (using the same venous access as the ICD lead) to the lateral right atrium for induction of AF. For acute defibrillation testing, a pulse generator emulator (Model 6967) with a surface area of 78.4 cm² was placed in the left subcutaneous pectoral pocket. All implanted lead components were manufactured by Cardiac Pacemakers Inc. (Guidant, St. Paul, Minnesota).

Atrial defibrillation testing. Measurement of the atrial defibrillation threshold was performed under conscious sedation with midazolam and fentanyl. Atrial fibrillation was induced with either high output ramp pacing or with alternating current stimulation. When AF had been sustained for >1 min, defibrillation testing was performed. The R-wave synchronized defibrillation shocks were delivered with an external defibrillator (ECD Model 2815, Cardiac Pacemakers), which delivers fixed 60/50 tilt biphasic shocks through a 125 μF capacitance. A step-up protocol was employed, starting at 0.5 J and increasing (1, 2, 3, 5, 8, 10, 15, 20 J) until there was restoration of sinus rhythm. The atrial defibrillation threshold was defined as the lowest energy shock to terminate atrial fibrillation. A threshold ≤3 J was defined prospectively as low energy to allow comparison with reduced output atrial defibrillators (9).

Two different shocking pathways were evaluated in each patient, with the order of testing randomized (Fig. 1). In the triad configuration, the distal right ventricular coil is the anode for the first phase of the biphasic shocks and the proximal right atrial coil and emulator are connected electrically as the cathode (13). The second shocking pathway was the transatrial configuration in which the proximal coil is the anode and the emulator is the cathode. The right ventricular coil was excluded from the system in this configuration.

Data analysis. The following variables were analyzed as possible predictors of atrial defibrillation threshold: age, gender, body surface area, past history of AF, amiodarone use in the previous three months, left ventricular ejection fraction and left atrial size as assessed by echocardiography. The relationships between continuous variables and atrial defibrillation threshold were assessed by linear regression using a least-squares algorithm. For discrete variables, unpaired t tests were performed. Multivariate analysis was then done on all variables with p < 0.10 by stepwise multiple logistic regression with the triad atrial defibrillation threshold as the dependent variable (StatMost 3.5, DataMost, Salt Lake City, Utah).

Analysis of the clinical characteristics of subjects with high atrial defibrillation thresholds was also performed. Patients were grouped by the prospectively defined cutoff of 3 J. Comparison of the high and low threshold groups were made using unpaired t tests for continuous variables and the Fisher exact test for discrete variables. Electrical parameters between the two lead configurations were compared using paired t tests. All data are presented as mean ± SD, and a p value <0.05 was considered significant.

RESULTS

Patient population. There were 34 consecutive patients enrolled in this study, and sustained AF could be induced in 32 of them who formed the study group. The subjects were 81% male with a mean age of 65 ± 10 years and a mean ejection fraction of 0.30 ± 0.14. Coronary artery disease with ischemic cardiomyopathy was the primary structural

Figure 1. A schematic representation of the defibrillation shocking pathways. The dual-coil transvenous lead is positioned so that the tip is in the right ventricular apex. (A) The triad configuration is shown in which the distal coil in the right ventricle serves as the anode (+) for defibrillation. The pectoral can is connected electrically to the proximal atrial coil and serves as the cathode (−). (B) The transatrial configuration is shown in which the can alone serves as the cathode with the proximal coil as the anode.
heart disease in 28 patients, 1 had idiopathic dilated cardiomyopathy and 3 patients had primary electrical disease with no known structural heart disease. At the time of implantation, 6 patients (19%) were receiving amiodarone. No patients were receiving other type I or type III antiarrhythmic drug therapy.

Atrial defibrillation. All patients tolerated the induction and termination of AF without complications. Specifically, there were no embolic events or ventricular arrhythmias induced with atrial defibrillation testing. Moreover, all patients were amnestic to the shocks following implantation. A mean of 8.9 ± 3.9 atrial defibrillation shocks were delivered per patient.

A summary of the electrical parameters measured at the atrial defibrillation threshold for the two shocking pathways is shown in Table 1. Atrial defibrillation energy requirements were reduced from 7.1 ± 6.0 J in the transatrial configuration to 4.0 ± 4.2 J in the triad configuration (p < 0.005). Thus, by delivering shocks between the ventricular coil and the atrial coil connected to the emulator, there was a 44% reduction of defibrillation thresholds compared with the shocking pathway between the right atrium and left pectoral emulator (Fig. 1).

Peak voltage at the atrial defibrillation threshold was reduced 26% in the triad configuration (p < 0.005). As expected, the shock impedance was also lowered significantly (18%) with the three-electrode, dual-coil triad configuration compared with the two-electrode, single-coil transatrial configuration. However, peak current did not differ significantly between the two configurations. This indicates that the reduction of impedance in the triad configuration is sufficient to account for the lowering of defibrillation threshold voltage and energy (13).

Histograms of the distributions of atrial defibrillation thresholds are shown in Figure 2. We prospectively defined defibrillation with ≤3 J as a low threshold, because this is the approximate energy requirement needed to implant a stand-alone atrial defibrillator with limited output capability (9). Low-energy thresholds were achieved in 69% (22 of 32) of subjects in the triad configuration, but only 47% (15 of 32) in the transatrial configuration (p = 0.06). The triad and optimal atrial defibrillation threshold histograms are very similar. In fact, the transatrial defibrillation threshold was more than 1 J lower than the triad in 17 patients (53%, p < 0.01). This suggests that the ability to program the shocking pathway in this patient population would offer little benefit.

The clinical characteristics of the patient population are shown in Table 2. The patients are grouped by the triad defibrillation threshold. Of the seven clinical variables assessed, only left atrial size differed significantly between the groups with high and low thresholds. Similarly, multivariate analysis, with left atrial size and age as independent variables (see Methods section), identified left atrial size as the only independent predictor of the triad atrial defibrillation threshold. A scatter plot of the relationship between defibrillation threshold and left atrial size is shown in Figure 3.

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Triad</th>
<th>Transatrial</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (J)</td>
<td>4.0 ± 4.2</td>
<td>7.1 ± 6.0</td>
<td>0.002</td>
</tr>
<tr>
<td>Voltage (V)</td>
<td>204 ± 102</td>
<td>275 ± 133</td>
<td>0.004</td>
</tr>
<tr>
<td>Current (A)</td>
<td>4.7 ± 2.6</td>
<td>5.4 ± 3.0</td>
<td>0.194</td>
</tr>
<tr>
<td>Impedance (Ω)</td>
<td>45 ± 6</td>
<td>55 ± 12</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

Figure 2. Distribution of atrial defibrillation thresholds. Histograms of atrial defibrillation thresholds (ADFT) are shown for the triad (top panel), transatrial (middle panel) and optimal (bottom panel) configurations. The optimal configuration was the configuration with the lower of the two defibrillation thresholds in the patient.

### Table 2. Comparison of Clinical Parameters of the High and Low Atrial Defibrillation Threshold Groups

<table>
<thead>
<tr>
<th></th>
<th>Low Threshold (≤3 J)</th>
<th>High Threshold (&gt;3 J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>22</td>
<td>10</td>
</tr>
<tr>
<td>Gender (% male)</td>
<td>86</td>
<td>70</td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>67 ± 9</td>
<td>60 ± 10</td>
</tr>
<tr>
<td>Body surface area (m²)</td>
<td>1.94 ± 0.19</td>
<td>1.99 ± 0.19</td>
</tr>
<tr>
<td>History of AF (%)</td>
<td>41</td>
<td>50</td>
</tr>
<tr>
<td>Amiodarone use (%)</td>
<td>14</td>
<td>30</td>
</tr>
<tr>
<td>Ejection fraction</td>
<td>0.30 ± 0.13</td>
<td>0.31 ± 0.17</td>
</tr>
<tr>
<td>LA size (cm)</td>
<td>4.1 ± 0.7</td>
<td>4.8 ± 0.7*</td>
</tr>
</tbody>
</table>

*p < 0.05.
animal studies have demonstrated the ability to achieve
not evaluated systematically in that study. Both human and
thresholds. However, atrial defibrillation thresholds were
induce AF may be useful to predict atrial defibrillation
suggesting that the use of low-energy shocks in sinus rhythm to
induction and termination of atrial fibrillation was consis-
tent with the upper limit of vulnerability hypothesis, sug-
mentions were lower in the triad configuration compared with
the transatrial configuration. Only left atrial size, among
those clinical parameters evaluated, showed a significant
correlation with the atrial defibrillation threshold.
Comparison with previous studies. Internal cardioversion
of atrial defibrillation was first reported nearly 30 years ago,
and since then, several animal and human studies have
confirmed the ability of transvenous shocks to defibrillate
AF (10–12,14,15). The shocking lead configuration, and
more recently the defibrillation waveform, have been shown
to be important determinants of defibrillation thresholds
(16,17). In general, the lowest thresholds are observed with
complex lead systems including defibrillation coils in the
coronary sinus, although these thresholds are not sufficiently
low to prevent pain in non-sedated subjects. Moreover, the
long-term safety and ability to extract these leads because of
infection or malfunction are unknown. Consequently, a
simple single lead that is easy to implant should be advan-
tageous for chronic systems.

There are limited data on the ability of standard ventric-
ular defibrillator lead systems to defibrillate AF. We previ-
ously showed that properly timed low-energy shocks could
induce AF, but defibrillation required shock energies ≥3 J
(18). Two lead systems were evaluated in that study, a right
atrial coil and left ventricular patch configuration and a
dual-coil transvenous lead. The relationship between the
induction and termination of atrial fibrillation was consis-
tent with the upper limit of vulnerability hypothesis, sug-
gesting that the use of low-energy shocks in sinus rhythm to
induce AF may be useful to predict atrial defibrillation
thresholds. However, atrial defibrillation thresholds were
not evaluated systematically in that study. Both human and
animal studies have demonstrated the ability to achieve
atrial defibrillation with a dual-coil transvenous lead
(19,20).

Ventricular proarrhythmia. The potential for atrial defi-
brillation shocks to induce ventricular fibrillation remains a
major concern (20–22), although to date this has not been
reported in clinical trials with the atrial defibrillator. How-
ever, reduced output atrial defibrillators have only under-
gone evaluation in patients without structural heart disease,
because backup ventricular defibrillation capabilities are not
present in these devices. It is noteworthy, therefore, that no
ventricular arrhythmias were induced with atrial defibrilla-
tion testing in the present study in which all but three
patients had a reduced ejection fraction. Although the
induction of ventricular arrhythmias is still undesirable with
atrial defibrillation shocks, the consequences are likely less
severe with ICD systems capable of ventricular defibrilla-
tion.

Clinical predictors of defibrillation threshold. Left atrial
size was the only clinical predictor of a high atrial defibril-
lation threshold. This is analogous to clinical predictors of
ventricular defibrillation thresholds, in which left ventricular
size or mass has been shown to predict high biphasic
thresholds (23,24). Studies of transthoracic atrial defibrilla-
tion have identified left atrial size and duration of AF as
predictors of high thresholds or unsuccessful cases (25,26).
The duration of AF is not a factor for defibrillation with
implantable systems because shocks are delivered acutely
after the onset of the arrhythmia.

Study limitations. Our study must be interpreted in the
face of certain methodologic limitations. First, defibrillation
thresholds of induced, but not spontaneous, AF were
measured. Therefore, it is possible that the lead configura-
tions tested would have a lower efficacy for the termination
of spontaneous AF. However, previous studies have shown
that defibrillation thresholds of induced AF are similar to
spontaneous AF (27,28). Moreover, at least 1 min of AF
was required before testing was begun, thus minimizing the
chance that AF terminated spontaneously rather than by the
delivered shock. Second, atrial defibrillation thresholds were
measured in two configurations, so it is possible that the
optimal shocking pathway for atrial defibrillation with this
single-pass lead was not identified. Finally, only a single
biphasic waveform was evaluated. Recently, it was shown
that a large capacitance waveform markedly reduced thresh-
holds (29). Therefore, it is possible that lower thresholds
could be obtained with other waveforms or capacitances and
this lead system.

Conclusions. This study demonstrated low atrial defibril-
lation thresholds using a single-pass transvenous ventricular
defibrillation lead with a conventional ventricular defibril-
lation pathway. Given the simplicity of implantation and
chronic stability of integrated ventricular defibrillation leads,
this single-lead, active pectoral configuration should be
considered as an alternative to the more complex multiple-

Figure 3. The relationship between left atrial size and atrial
defibrillation threshold. A scatter plot is presented. The line is the
linear regression fit of the data.

DISCUSSION

The major finding of this study was the high efficacy of a
single-pass, dual-coil transvenous ventricular defibrillator
lead to terminate induced AF. Defibrillation energy require-
ments were lower in the triad configuration compared with
the transatrial configuration. Only left atrial size, among
those clinical parameters evaluated, showed a significant
correlation with the atrial defibrillation threshold.

Comparison with previous studies. Internal cardioversion
of atrial defibrillation was first reported nearly 30 years ago,
and since then, several animal and human studies have
confirmed the ability of transvenous shocks to defibrillate
AF (10–12,14,15). The shocking lead configuration, and
more recently the defibrillation waveform, have been shown
to be important determinants of defibrillation thresholds
(16,17). In general, the lowest thresholds are observed with
complex lead systems including defibrillation coils in the
coronary sinus, although these thresholds are not sufficiently
low to prevent pain in non-sedated subjects. Moreover, the
long-term safety and ability to extract these leads because of
infection or malfunction are unknown. Consequently, a
simple single lead that is easy to implant should be advan-
tageous for chronic systems.

There are limited data on the ability of standard ventric-
ular defibrillator lead systems to defibrillate AF. We previ-
ously showed that properly timed low-energy shocks could
induce AF, but defibrillation required shock energies ≥3 J
(18). Two lead systems were evaluated in that study, a right
atrial coil and left ventricular patch configuration and a
dual-coil transvenous lead. The relationship between the
induction and termination of atrial fibrillation was consis-
tent with the upper limit of vulnerability hypothesis, sug-
gesting that the use of low-energy shocks in sinus rhythm to
induce AF may be useful to predict atrial defibrillation
thresholds. However, atrial defibrillation thresholds were
not evaluated systematically in that study. Both human and
animal studies have demonstrated the ability to achieve
atrial defibrillation with a dual-coil transvenous lead
(19,20).

Ventricular proarrhythmia. The potential for atrial defi-
brillation shocks to induce ventricular fibrillation remains a
major concern (20–22), although to date this has not been
reported in clinical trials with the atrial defibrillator. How-
ever, reduced output atrial defibrillators have only under-
gone evaluation in patients without structural heart disease,
because backup ventricular defibrillation capabilities are not
present in these devices. It is noteworthy, therefore, that no
ventricular arrhythmias were induced with atrial defibrilla-
tion testing in the present study in which all but three
patients had a reduced ejection fraction. Although the
induction of ventricular arrhythmias is still undesirable with
atrial defibrillation shocks, the consequences are likely less
severe with ICD systems capable of ventricular defibrilla-
tion.

Clinical predictors of defibrillation threshold. Left atrial
size was the only clinical predictor of a high atrial defibril-
lation threshold. This is analogous to clinical predictors of
ventricular defibrillation thresholds, in which left ventricular
size or mass has been shown to predict high biphasic
thresholds (23,24). Studies of transthoracic atrial defibrilla-
tion have identified left atrial size and duration of AF as
predictors of high thresholds or unsuccessful cases (25,26).
The duration of AF is not a factor for defibrillation with
implantable systems because shocks are delivered acutely
after the onset of the arrhythmia.

Study limitations. Our study must be interpreted in the
face of certain methodologic limitations. First, defibrillation
thresholds of induced, but not spontaneous, AF were
measured. Therefore, it is possible that the lead configura-
tions tested would have a lower efficacy for the termination
of spontaneous AF. However, previous studies have shown
that defibrillation thresholds of induced AF are similar to
spontaneous AF (27,28). Moreover, at least 1 min of AF
was required before testing was begun, thus minimizing the
chance that AF terminated spontaneously rather than by the
delivered shock. Second, atrial defibrillation thresholds were
measured in two configurations, so it is possible that the
optimal shocking pathway for atrial defibrillation with this
single-pass lead was not identified. Finally, only a single
biphasic waveform was evaluated. Recently, it was shown
that a large capacitance waveform markedly reduced thresh-
holds (29). Therefore, it is possible that lower thresholds
could be obtained with other waveforms or capacitances and
this lead system.

Conclusions. This study demonstrated low atrial defibril-
lation thresholds using a single-pass transvenous ventricular
defibrillation lead with a conventional ventricular defibril-
lation pathway. Given the simplicity of implantation and
chronic stability of integrated ventricular defibrillation leads,
this single-lead, active pectoral configuration should be
considered as an alternative to the more complex multiple-
lead systems now in clinical trials. These data support the
development of the combined atrial and ventricular ICD
system, although further studies are needed to identify
optimal defibrillation pathways and waveforms.

Reprint requests and correspondence: Dr. Michael R. Gold,
Division of Cardiology, N3W77, University of Maryland Medical
System, 22 South Greene Street, Baltimore, Maryland 21201.
E-mail: MGold@medicine.ab.umd.edu.

REFERENCES

2. The Antiarrhythmics Versus Implantable Defibrillators (AVID) Investiga-
tors. A comparison of antiarrhythmic-drug therapy with im-
plantable defibrillators in patients resuscitated from near-fatal ventric-
4. Grimm W, Flores B, Marchlinski F. Symptoms and electrocardio-
graphically documented rhythm preceding spontaneous shocks in
patients with implantable cardioverter-defibrillators. Am J Cardiol
6. Cooper RA, Johnson EE, Wharton JM. Internal atrial defibrillation in
patients with a history of ventricular tachycardia: effects of rate and
7. Marked reduction in internal atrial defibrillation thresholds with
short duration atrial tachyarrhythmias in humans using a single lead
8. Gold MR, Foster AH, Shorofsky SR. Effects of an active pectoral-
pulse generator shell on defibrillation efficacy with a transvenous lead
11. Alferness CA, Smith WM, Ideker RE. Internal cardio-
version of atrial fibrillation in sheep. Circulation 1993;87:1673–86.
13. Florin TJ, Weiss DN, Peters RW, Shorofsky SR, Gold MR. Induc-
tion of atrial fibrillation with low-energy defibrillator shocks in
patients with implantable cardioverter-defibrillators. Am J Cardiol
19. Raitt MH, Johnson G, Dolack GL, Poole JE, Kudenchuck PJ, Bardy GH. Clinical predictors of the defibrillation threshold with the
unipolar implantable defibrillation system. J Am Coll Cardiol 1995;
23. Timmermans C, Rodriguez RM, Ayers GM, Lambert H, Smeets J, Wellens HJ. Effect of electrode length on atrial defibrillation thresh-
25. Alferness CA, Smith WM, Ideker RE. Internal cardio-
version of atrial fibrillation in sheep. Circulation 1993;87:1673–86.
30. Florin TJ, Weiss DN, Peters RW, Shorofsky SR, Gold MR. Induc-
tion of atrial fibrillation with low-energy defibrillator shocks in
patients with implantable cardioverter-defibrillators. Am J Cardiol
36. Raitt MH, Johnson G, Dolack GL, Poole JE, Kudenchuck PJ, Bardy GH. Clinical predictors of the defibrillation threshold with the
unipolar implantable defibrillation system. J Am Coll Cardiol 1995;
40. Timmermans C, Rodriguez RM, Ayers GM, Lambert H, Smeets J, Wellens HJ. Effect of electrode length on atrial defibrillation thresh-