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Glover, B. M., McCann, C. J., Manoharan, G., Walsh, S. J., Moore, M. J., Allen, J. D., Escalona, O., Mc, A. J., Trouton, T. G., Stevenson, M., Roberts, M. J., & Adgey, A. J. (2008). A pilot study of a low-tilt biphasic waveform for transvenous cardioversion of atrial fibrillation: improved efficacy compared with conventional capacitor-based waveforms in patients. *PACE*, 31(8), 1020-1024.

Published in:
PACE

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A Pilot Study of a Low-Tilt Biphasic Waveform for Transvenous Cardioversion of Atrial Fibrillation: Improved Efficacy Compared with Conventional Capacitor-Based Waveforms in Patients

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Background: The optimal waveform tilt for defibrillation is not known. Most modern defibrillators used for the cardioversion of atrial fibrillation (AF) employ high-tilt, capacitor-based biphasic waveforms.

Methods: We have developed a low-tilt biphasic waveform for defibrillation. This low-tilt waveform was compared with a conventional waveform of equivalent duration and voltage in patients with AF. Patients with persistent AF or AF induced during a routine electrophysiology study (EPS) were randomized to receive either the low-tilt waveform or a conventional waveform. Defibrillation electrodes were positioned in the right atrial appendage and distal coronary sinus. Phase 1 peak voltage was increased in a stepwise progression from 50 V to 300V. Shock success was defined as return of sinus rhythm for ≥ 30 seconds.

Results: The low-tilt waveform produced successful termination of persistent AF at a mean voltage of 223 V (8.2 J) versus 270 V (6.7 J) with the conventional waveform ($P = 0.002$ for voltage, $P = ns$ for energy). In patients with induced AF the mean voltage for the low-tilt waveform was 91V (1.6 J) and for the conventional waveform was 158 V (2.0 J) ($P = 0.005$ for voltage, $P = ns$ for energy). The waveform was much more successful at very low voltages (less than or equal to 100 V) compared with the conventional waveform (Novel: 82% vs Conventional 22%, $P = 0.008$).

Conclusion: The low-tilt biphasic waveform was more successful for the internal cardioversion of both persistent and induced AF in patients (in terms of leading edge voltage). (PACE 2008; 31:1020–1024)

atrial fibrillation, direct current cardioversion

Introduction and Background

Restoration of sinus rhythm is an important strategy for patients with symptomatic atrial fibrillation (AF). Internal cardioversion can be used at low voltages for patients in whom AF is stimulated during an electrophysiology study (EPS), which does not spontaneously revert,¹ during AF ablation² or in cases of failed transthoracic direct current cardioversion. The ideal principle in all these cases is to develop a waveform, which is highly successful at a low voltage, thus limiting the number of shocks required. Various waveform

parameters have been studied in order to increase success. We have previously shown that low-tilt monophasic^{3,4} and biphasic⁵ waveforms are more successful than conventional higher tilt capacitor-based waveforms for the cardioversion of AF in the laboratory. The aim of this pilot study was to investigate if the low-tilt biphasic waveform was more successful and could be delivered safely in patients with persistent and induced AF. We therefore compared a low-tilt biphasic waveform with a conventional waveform for the internal cardioversion of persistent and inducible AF in patients (all other waveform parameters were identical and set according to previously published work).^{3–5}

Methods

Patients with a history of persistent AF and patients with AF induced during an EPS for investigation of a supraventricular tachycardia (SVT) were invited to participate. Permission was granted from the local ethics committee. Patients with persistent AF had to be anticoagulated for at

Funding Source: Northern Ireland Chest, Heart and Stroke Association.

Conflicts of Interest: None.

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Received January 29, 2008; revised March 13, 2008; accepted May 4, 2008.

least 4 weeks prior to the procedure. Exclusion criteria were: any history of thromboembolism, intracardiac thrombus, inability to take oral anticoagulation, complete heart block, angina pectoris at rest, severe disease of native valves, or the presence of prosthetic valves or an inability to give written informed consent.

The procedure was carried out under aseptic technique in a cardiac catheterization laboratory. Patients were randomized to either the low-tilt biphasic waveform or a conventional-tilt waveform. Both waveforms were of 12-ms duration (each phase 6 ms) and the second phase was 50% of the first phase (Fig. 1). These parameters had previously been studied in the laboratory and were found to be the most efficacious.⁵ The low-tilt waveform was delivered from a specially designed defibrillator with a 1 μ F capacitor, which rapidly and repeatedly discharged in order to minimize the tilt in both the positive and negative phase. Being such a small capacitor meant that each discharge and subsequent charge was so rapid that over each 6-ms phase the overall waveform tilt was close to zero. The conventional waveform was delivered from a Ventritex HVS-02 defibrillator with a single discharge from a 150 μ F capacitor (Ventritex, Sunnyvale, CA, USA).

Figure 1. Voltage recording for the low-tilt biphasic waveform (top) and conventional biphasic waveform (bottom).

Shocks were synchronized to the R wave and were not delivered if the preceding R-R interval was < 500 ms (to minimize the risk of precipitating ventricular arrhythmias).⁶ Single-use, 6.5 Fr defibrillation catheters (Rhythm Technologies, Irvine, CA, USA) were positioned in the right atrial appendage and distal coronary sinus. Defibrillation was then carried out in a step-up voltage protocol until sinus rhythm was achieved or until a maximum phase 1 leading edge voltage of 300 V had been achieved. Waveform voltages were: 50/–25 V, 100/–50 V, 150/–75 V, 200/–100 V, 240/–120 V, 280/–140 V, 300/–150 V. Shock success was defined as the restoration of sinus rhythm for $\geq$ 30 seconds after shock delivery.

For patients with persistent AF, anticoagulation was stopped 48 hours prior to the procedure and low molecular weight heparin was administered periprocedurally (1mg/kg of enoxaparin). Oral anticoagulation was resumed and the heparin was discontinued when a therapeutic international normalized ratio (INR) was achieved. AF was induced by right atrial pacing ($\geq$ 300/min) for those undergoing EP study. Cardioversion was only performed if the AF was sustained for a minimum period of 30 seconds.

Statistics

Cardioversion success was compared for each defibrillator using Fisher's exact test. The Mann-Whitney test was used for nonparametric variables. All calculations were performed with SPSS Version 11 (SPSS Inc, Chicago, IL, USA). $P < 0.05$ was considered statistically significant. The local Ethics committee approved the study.

Results

A total of 45 patients were enrolled. Of these, 25 had persistent AF (low-tilt waveform, $n = 13$; conventional waveform, $n = 12$) and 20 had AF induced during an EPS (low-tilt waveform, $n = 11$; conventional waveform, $n = 9$). Baseline characteristics are summarized in Table I. There were no significant differences between the two groups. A total of 178 shocks were delivered. There was no significant arrhythmia following the delivery of any shock, or elevation of cardiac troponin I (>0.01 ng/mL) following any procedure. There were no cases of thromboembolism associated with the procedure or during routine follow-up.

The low-tilt biphasic waveform significantly reduced the peak voltage required for successful cardioversion in patients with both persistent and induced AF. In patients with persistent AF the mean leading edge voltage was 223 V compared with 270 V of patients randomized to the conventional waveform ($P = 0.005$). At low voltages (i.e.,

Table I.

Baseline Patient Characteristics and Parameters for Successful Shocks for the Low-Tilt and Conventional Waveform in Persistent and Inducible AF

AF Type	Parameter	Low Tilt	Conventional	P
Persistent AF n = 25	Mean age $\pm$ SD (years)	62 $\pm$ 14	62 $\pm$ 12	Ns
	Male (%)	7 (54%)	11 (92%)	0.03
	Mean LA diameter $\pm$ SD (mm)	44 $\pm$ 6	44 $\pm$ 6	Ns
	Median AF duration (IQR, months)	4 (2–22)	4 (4–6)	Ns
	Previous failed external DCCs	3	1	Ns
	Etiology of AF	HTN (%)	7 (55%)	Ns
		VHD (%)	4 (30%)	Ns
		CAD (%)	2 (15%)	Ns
		Class I (%)	1 (8%)	Ns
		Class II (%)	9 (70%)	Ns
		Class III (%)	2 (15%)	Ns
		Class IV (%)	2 (15%)	Ns
Low tilt n = 13	Mean voltage $\pm$ SD (V)	223 $\pm$ 65	270 $\pm$ 42	0.002
	Mean energy $\pm$ SD (J)	8.2 $\pm$ 2.6	6.7 $\pm$ 4.5	Ns
	Mean impedance $\pm$ SD (Ohms)	53 $\pm$ 10	56 $\pm$ 10	Ns
	Success ($\leq$ 300V)	10 (77%)	2 (17%)	0.005
Conventional n = 12				
Induced n = 20	Mean age $\pm$ SD (years)	40 $\pm$ 21	49 $\pm$ 13	Ns
	Male (%)	5 (45%)	4 (44%)	Ns
	History of AVRT (%)	7 (64%)	5 (56%)	Ns
	History of AVNRT (%)	3 (27%)	2 (22%)	Ns
	History of atrial flutter (%)	1 (9%)	2 (22%)	Ns
	Mean voltage $\pm$ SD (V)	91 $\pm$ 37	158 $\pm$ 54	0.005
	Mean energy $\pm$ SD (J)	1.6 $\pm$ 1.2	2.0 $\pm$.5	
	Mean impedance $\pm$ SD (Ohms)	49 $\pm$ 8	45 $\pm$ 5	Ns
Low tilt n = 11	Success at $\leq$ 100V*	(82%)	(22%)	0.008
Conventional n = 9				

*Post hoc analysis.

Abbreviations: LA = left atrium; HTN = hypertension; VHD = valvular heart disease; CAD = coronary artery disease; AVRT = AV reentry tachycardia; AVNRT = AN nodal reentry tachycardia; SD = standard deviation; IQR = interquartile range.

$\leq$ 300V) the low-tilt waveform was successful in 77% of cases compared with only 17% of cases using the conventional tilt.

In patients with induced AF the mean leading edge voltage was 91 V for the low-tilt waveform and 158V for the conventional waveform (P = 0.005).

There was no significant difference in the mean energy between both waveforms for either persistent (Low-tilt 8.2 J vs Conventional-tilt 6.7 J) or induced AF (Low-tilt 1.6 J vs Conventional-tilt 2.0 J).

Discussion

This study shows that a low-tilt waveform lowers the voltage required for the cardioversion of both persistent and induced AF. Our results compare favorably with other studies of internal cardioversion in patients with both persistent and inducible AF (see Table II). Prior to this study the lowest mean leading edge voltage reported for the internal cardioversion of persistent AF was 290 V (biphasic waveform with 65% tilt)⁷ and 173 V (biphasic with a rounded first phase) for induced AF.⁸ These findings, that a low-tilt

Table II.

Summary of Results for the Internal Cardioversion of Persistent and Induced AF from Previous Studies Altering Waveform Parameters

Author	Type of AF	Waveform Type	Tilt	Pulse Width (ms)	Catheter Position	Mean Leading Edge Voltage ($\pm$ Range)
Boriani et al. ⁷	Persistent	Biphasic	65%	3.0/3.0	RA, CS	337 $\pm$ 104
Boriani et al. ⁷	Persistent	Biphasic	65%	6.5/2.5	RA, CS	290 $\pm$ 76
Andraghetti et al. ¹²	Persistent	Biphasic	50%	6.0/6.0	RA, CS	320 $\pm$ 45
Gasparini et al. ¹³	Persistent	Biphasic	65%	6.0/6.0	RA, CS / LPA	320 $\pm$ 60
Tse et al. ¹⁴	Persistent	Biphasic	60%	3.0/3.0	RA, CS	343 $\pm$ 8
Lévy et al. ¹⁵	Persistent	Biphasic	60%	3.0/3.0	RA, CS	311 $\pm$ 60
Schmitt et al. ¹⁶	Persistent	Biphasic	65%	3.0/2.0	RA, CS / PA	—
Boriani et al. ⁷	Persistent	Biphasic	60%	3.0/3.0	RA, CS / LPA	345 $\pm$ 64
Ammer et al. ¹⁷	Persistent	Biphasic	65%	3.0/3.0	RA, CS	355
Ammer et al. ¹⁷	Persistent	Biphasic	65%	6.0/6.0	RA, CS	254
Socas et al. ¹⁸	Persistent	Biphasic	60%	3.0/2.0	RA, CS / PA	300 $\pm$ 68
Mairesse et al. ¹⁹	Persistent	Monophasic	—	—	RA, CS	—
Mairesse et al. ¹⁹	Persistent	Biphasic	—	—	RA, CS	—
Murgatroyd et al. ²⁰	Induced	Biphasic	65%	3.0/3.0	RA, CS	230 $\pm$ 55
Harbinson et al. ²¹	Induced	Biphasic	Rounded 1st phase	3.0/3.0	RA, CS	173
Cooper et al. ²²	Induced	Biphasic	60%	7.5/2.5	RA, CS	166 $\pm$ 67
Cooper et al. ²²	Induced	Biphasic	60%	5.0/5.0	RA, CS	241 $\pm$ 35
Cooper et al. ²²	Induced	Monophasic	60%	10ms	RA, CS	320 $\pm$ 84
Socas et al. ¹⁸	Induced	Biphasic	65%	3.0/2.0	RA, CS / PA	270 $\pm$ 67
Tse et al. ¹⁴	Induced	Biphasic	60%	3.0/3.0	RA, CS	192 $\pm$ 15
Jung et al. ²³	Induced	Biphasic	40%	2.0/2.0	RA,CS	97 $\pm$ 35
Jung et al. ²³	Induced	Biphasic	80%	2.0/2.0	RA,CS	252 $\pm$ 64

Abbreviations: RA = right atrial; CS = coronary sinus; PA = pulmonary artery.

waveform lowers the peak voltage for successful cardioversion, support previous laboratory studies.^{3–5} It has been shown in several studies that peak voltage is directly related to shock tolerability rather than the total delivered energy for internal cardioversion.^{9,10} Although there is always a level of discomfort associated with all shocks it can be postulated that lowering the mean voltage and increasing the overall success at low voltages is beneficial in improving tolerability to the extent that this may reduce the sedation requirements for internal cardioversion. This parameter was not directly looked at in this study. It must also be noted that there was no significant difference in the total energy required for the successful cardioversion of both persistent and induced AF. Lower tilt waveforms are generally associated with a higher total energy. Interestingly, this was not significantly

higher (and in fact was slightly lower in the induced cases) with our low-tilt waveform.

There are several theoretical explanations why lowering the waveform tilt may increase shock success. The lower success of conventional capacitor-based waveforms can be correlated with the fundamental law of electrostimulation.¹¹ Failure of defibrillation may be due to lack of depolarization in the periphery of the defibrillation field (farfield). The area of myocardium that is furthest from the electrodes may not be exposed to a high enough defibrillating voltage throughout the duration of the shock. In contrast, low-tilt waveforms maintain a steady potential difference throughout the shock duration.

This study is limited by small patient numbers but provides useful information that may prompt further work in the cardioversion of AF as well

as in standard external cardiac defibrillators and ventricular defibrillation. The technology required to produce this low-tilt waveform is simple and could easily be incorporated into an implantable device.

Conclusions

This novel low-tilt biphasic waveform was highly successful for the cardioversion of both

persistent and inducible AF at a very low leading edge voltage extending our previous findings into the clinical arena. This waveform could be used for the cardioversion of AF during electrophysiology studies as well as in patients who have had failed transthoracic cardioversions. It should also prompt further work into optimizing waveform tilt for the defibrillation of ventricular arrhythmias.

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