A comparison of transoesophageal atrial pacing and direct current cardioversion for the termination of atrial flutter: a prospective, randomised clinical trial

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Abstract

Objective—To compare the safety and efficacy of transoesophageal atrial pacing (TAP) with an easily swallowed pill electrode and direct current cardioversion (DCC) in patients with atrial flutter that was refractory to appropriate medical treatment.

Design—Prospective, randomised clinical trial.

Setting—Community based United States naval hospital.

Subjects—Twenty one consecutive patients with refractory atrial flutter selected consecutively from the inpatient cardiology consultation service. All patients were haemodynamically stable and medical treatment with a class IA or IC antiarrhythmic agent had failed. Eleven patients were treated with TAP and 10 patients were treated with DCC.

Interventions—Digoxin was given to all patients to control the ventricular rate to <100/minute.

Main outcome measure—Conversion to normal sinus rhythm and arrhythmias after cardioversion.

Results—Conversion to normal sinus rhythm was similar in both groups (TAP 8/11, DCC 9/10, $p = 0.31$). Arrhythmias after cardioversion including third degree heart block and non-sustained ventricular tachycardia were more frequent in the DCC group (TAP 0/11, DCC 6/10, $p = 0.02$).

Conclusion—Transoesophageal atrial pacing with an easily swallowed pill electrode is safe, well tolerated, and is as efficacious as DCC for refractory atrial flutter.

(Br Heart J 1993;69:530-535)

The closeness of the distal oesophagus to the atria of the heart has been used to record atrial electrocardiograms since 1906, when Max Cremer passed a 10 x 15 cm electrode into the throat of a professional sword swallower.¹ Transoesophageal electrodes have been useful for differentiating supraventricular tachycardia from ventricular tachycardia, for defining mechanisms of supraventricular tachycardia, in the measurement of interatrial conduction times, and most recently, for delivery of electrical stimuli to the atria for diagnostic and therapeutic purposes.

Atrial flutter is a relatively common supraventricular tachyarrhythmia. Because of

haemodynamic instability encountered with this arrhythmia, it is desirable to convert atrial flutter to normal sinus rhythm. Although medical treatment with agents that prolong the myocardial refractory period are usually attempted, these agents generally fail to end the arrhythmia.² Direct current cardioversion (DCC) offers a highly effective technique to end atrial flutter; however, this method requires light anaesthesia and may be poorly tolerated by a significant proportion of patients with atrial flutter, particularly those patients treated with digoxin to control the ventricular response rate.³⁻⁵

To end atrial flutter by rapid overdrive atrial pacing is an alternative to DCC. Rapid pacing from the oesophagus is feasible and has been used to end atrial flutter.⁶⁻⁸ Initial studies of transoesophageal atrial pacing (TAP) used large electrodes designed for transvenous pacing and that required nasal or oral intubation. A recent innovation has been the development of an easily swallowed oesophageal pill electrode.⁹ Clinical evaluation of this has been limited to paediatric¹⁰ and unselected adult populations.¹¹ This report presents the results of a prospective, randomised clinical trial comparing TAP with DCC to end atrial flutter in a selected population of patients in whom appropriate antiarrhythmic medication has failed.

Patients and methods

PATIENTS

All patients referred to the cardiology consultation service at the Naval Hospital, Oakland, California with refractory atrial flutter were prospectively evaluated for entry into the trial. Twenty four consecutive patients with refractory atrial flutter were evaluated. Two patients were excluded because of their inability to give informed consent and one patient was excluded because of oesophageal stricture that impaired the patient's ability to swallow the pill electrode. Patients were also excluded if they had electrocardiographic evidence of Wolffe-Parkinson-White syndrome or were haemodynamically unstable and considered to require immediate DCC. These criteria, however, were not found in our consecutive series of patients. Atrial flutter was recorded on a 12 lead electrocardiogram in all subjects and was verified by one of the investigators. In subjects in whom the rhythm was indeterminate on a surface electrocardiogram, an oesophageal electrocardiogram was performed. Twenty one patients were accepted

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Accepted for publication
5 October 1992.

for randomisation including 15 men (age range 60–88) and six women (age range 64–76). One patient was studied twice for separate episodes of atrial flutter. All patients received digoxin to control their ventricular rates. Antiarrhythmic treatment consisted of procainamide (1.0 g intravenous loading dose followed by 750 mg oral maintenance dose every six hours) in 14 patients, quinidine sulphate (oral loading dose of 600 mg followed by 400 mg oral maintenance dose every six hours) in five patients, and flecainide acetate (150 mg oral maintenance dose every 12 h) in two patients. Choice of antiarrhythmic medication was left to the discretion of the

patient's attending physician and was continued throughout the study. The study was reviewed and approved by the committee on human research at the Naval Hospital, Oakland, California. The nature of all procedures in the study was explained fully and written informed consent was obtained from all patients.

TRANSEOESOPHAGEAL ATRIAL PACING STUDY GROUP

After patients had nothing by mouth for at least six hours, they were asked to swallow the oesophageal pill electrode (Tapsule pill electrode, Arzco Medical Electronics, Chicago, Illinois) to a depth of 40 cm from the mouth. This bipolar electrode measures 20×3 mm. It contains two 6×3 mm stainless steel conducting members separated by an interelectrode spacing of 14 mm. The electrode is enclosed in a white gelatin capsule which rapidly dissolves after being swallowed, and is connected to a pair of thin wires that are intertwined for a distance of 50 cm. After swallowing the electrode, the connecting wires were attached to a standard electrocardiograph machine (Marquette MAC 12-lead ECG) through the Tapsule Pill Electrode extender cable and oesophageal preamplifier (fig 1). Simultaneous surface leads II, V1, V5, V6, and a bipolar transoesophageal electrocardiogram (E) were recorded at a paper speed of 50 mm/s. A composite (C) tracing of lead II and lead E was also recorded. The pill electrode was then withdrawn slowly and positioned at the site in the oesophagus recording the largest amplitude of the bipolar atrial electrocardiogram (fig 2). The electrode wires were then disconnected from the oesophageal preamplifier and connected to the transoesophageal cardiac stimulator (Arzco transoesophageal cardiac stimulator, Model 7). This stimulator provides square wave constant current pulses ranging from 0–10 mA, pulse duration from 0–10 ms, and pacing duration rates from 60–600 pulses/min. Pacing protocol was carried out as follows:

(a) To avoid inadvertent rapid ventricular stimulation, a 10 s test stimulus was given at 15 mA with a pulse width of 10 ms. Test stimulus pacing rates were given at 20 pulses/min greater than the intrinsic ventricular rate. If ventricular capture was noticed, then the electrode was repositioned 1.0 cm higher in the oesophagus.

(b) After ascertaining that there was no ventricular capture, pacing was started at a rate 25% greater than the intrinsic atrial rate. Pulse width was kept constant throughout the protocol at 10 ms. Pacing currents were initiated at 15 mA and increased in 5 mA increments at 30 s intervals to a maximum of 40 mA until atrial capture was noted. If the atria failed to capture, then the electrode was repositioned at a site 1.0 cm higher in the oesophagus and the protocol repeated.

(c) Once atrial capture was achieved, pacing rates were increased to 40% greater than the intrinsic rate and maintained for a maxi-

Figure 1 Patient cable connections with the oesophageal pill electrode and preamplifier used to obtain oesophageal electrocardiograms. When the electrode is properly positioned over the left atrium (LA), the extender cable is disconnected and a cardiac stimulator is attached to the pill electrode for atrial pacing.

Figure 2 Transoesophageal electrocardiograms (E) with simultaneous surface leads II, V1, V5, V6, and a composite lead (C) of II and E. Atrial rate is 300 and ventricular rate is 75.

Figure 3 Electrocardiographic tracings recorded in a patient at the time of transoesophageal atrial pacing cardioversion. (A) Oesophageal electrocardiogram (E) before pacing with atrial rate=290. (B) Atrial pacing at a rate of 400 with conversion to normal sinus rhythm.

Figure 4 Electrocardiographic tracings recorded in a patient at the time of transoesophageal atrial pacing cardioversion. (A) Oesophageal electrocardiogram (E) before pacing with atrial rate=310. (B) Atrial pacing at a rate of 450 with resultant rhythm of atrial fibrillation. (C) Spontaneous conversion of atrial fibrillation to normal sinus rhythm that occurred about five seconds after the end of atrial pacing.

imum of 120 s. Pacing ended sooner with conversion to normal sinus rhythm (fig 3), atrial fibrillation (fig 4), or at the request of the patient. If the rhythm did not change, then steps 1 and 2 were repeated. Once atrial capture occurred, pacing rates were increased to 50% greater than the intrinsic rate and maintained for 20 s. If required, subsequent increases in pacing rate were started at increments of 10 pulses/min every 20 s to a maximum pacing rate of 600/min.

(d) No sedatives or analgesics were used.

DIRECT CURRENT CARIOVERSION STUDY GROUP

Patients were allowed nothing by mouth for six hours before DCC. A staff anaesthesiologist was in attendance at all cases and gave sodium thiopental and diazepam to provide a five to 10 minute interval of light anaesthesia. The anterior chest wall was shaved and 3.5 inch external electrode gelpads were placed over the apex and base of the heart according to the American Heart Association Advanced Cardiac Life Support (ACLS) recommendations.¹² This configuration is standard at the Naval Hospital, Oakland, California in adherence with the ACLS guidelines, although there is evidence that anterior posterior patch configurations may be more efficient.¹³ Synchronised direct current countershock was applied with a standard defibrillator (Hewlett-Packard Defibrillator/Monitor Model 78620A). An initial shock of 25 J was given and repeated if necessary. Subsequent shocks were given at 25 J increments up to a maximum of 100 J until atrial flutter ended. One patient received an additional shock at 200 J.

STATISTICAL ANALYSIS

Data are expressed as mean (SD) for continuous data and proportions for nominal data. Comparisons between groups were made with the Student's *t* test (unpaired, two tailed) for continuous data and χ^2 (2×2 , with continuity correction) for nominal data. A *p* value <0.05 was considered statistically significant.

Results

CLINICAL CHARACTERISTICS

Table 1 shows the age, sex, atrial rate, left atrial dimension, and prevalence of atherosclerotic coronary artery disease (ASCAD). Also table 1 shows the TAP electrode depth, pacing energies, total cardioversions, and cardioversion energies required to end the arrhythmia. Eighteen of 21 patients had documented ASCAD. Mean age was 70 (7.2) years (range 60–88). Mean atrial rate was 293.6 (27) (range 215–315). Ventricular rates were controlled with digoxin in all patients. Mean left atrial dimension was 44.0 (6.1) cm (range 28–52).

The mean depth of the transoesophageal pill electrode at which cardioversion was attempted was 34.3 (1.7) (range 32–38) cm.

Table 1 Patient distribution and clinical characteristics

Patient	Study group	Flutter rate	Sex	Age	TAP electrode depth (cm)	Pacing energy (mA)	CV	Final energy (J)	LAD (cm)	ASCAD	Conversion to NSR
1	DCC	310	M	77	—	—	2	25	41	—	+
2	TAP	315	M	72	38	30	—	—	50	—	+
3	TAP	290	M	64	33	20	—	—	49	+	+
4	TAP	300	M	88	34	20	—	—	42	+	+
5	DCC	300	F	64	—	—	5	200	46	+	—
6	DCC	290	M	76	—	—	1	25	28	+	+
7	DCC	215	M	83	—	—	1	25	39	+	+
8	TAP	300	M	74	34	20	—	—	46	+	+
9	DCC	215	M	66	—	—	2	25	50	+	+
10	TAP	310	F	68	33	40	—	—	32	+	+
11	TAP	300	M	60	35	30	—	—	48	+	—
12	DCC	300	M	60	—	—	1	25	48	+	+
13	DCC	310	M	62	—	—	1	25	46	+	+
14	TAP	300	F	66	33	30	—	—	42	—	+
15	DCC	290	M	75	—	—	1	25	52	+	+
16	DCC	300	F	76	—	—	1	25	35	+	+
17	TAP	290	M	73	35	40	—	—	48	+	—
18	TAP	300	F	64	32	40	—	—	46	+	—
19	TAP	315	M	69	34	30	—	—	44	+	+
20	DCC	315	F	71	—	—	1	25	42	+	+
21	TAP	300	F	72	36	20	—	—	50	+	+
Totals(mean (SD))		293.6 (27)		70 (7.2)	34.3 (1.7)	29.1 (8.3)			44 (6.1)		

TAP, transoesophageal atrial pacing; LAD, left atrial dimension; NSR, normal sinus rhythm; DCC, direct current cardioversion; ASCAD, atherosclerotic coronary artery disease; CV, cardioversions.

Pacing energies that produced cardioversion ranged from 20–40 mA, with a mean of 29.1 (8.3) mA. In seven patients in the DCC group, a single 25 J shock produced cardioversion. Two patients required a second cardioversion at 25 J. One patient failed to be converted to normal sinus rhythm after five cardioversions with a final energy of 200 J.

Table 2 shows the comparability between groups. Both groups were comparable with regards to age, sex, atrial rate, left atrial dimension, presence of ASCAD, and concurrent use of digoxin and class IA antiarrhythmic agents. Duration of atrial flutter was indeterminate in three patients in the DCC group and two patients in the TAP group. A trend towards increased duration of atrial flutter at the time of electrical cardioversion was noticed in the TAP group, but this was not statistically significant (TAP 7.2 (4.8); DCC 5.3 (3.9) days, $p = 0.09$).

MORBIDITY OR MORTALITY

There were no deaths in this study. Conversion to normal sinus rhythm was seen in eight of 11 (72.7%) patients in the TAP group compared with nine of 10 (90%) patients in the DCC group ($p = 0.31$). Six patients in the TAP group showed a transient period of atrial fibrillation before conversion to normal sinus rhythm. Transient epigastric burning was noted in all patients who underwent TAP. The burning sensation was limited to periods of pacing and was generally well tolerated for short periods (less than two minutes). Prolonged epigastric burning or discomfort after pacing was not found. Non-

cardiac chest pain was noticed in five of 10 patients after DCC but not in the TAP group. In all five cases, an electrocardiogram was taken to exclude ischaemic cardiac pain. No incidences of cardiac chest pain, chest burns, or dysphagia were found. Arrhythmias after cardioversion were seen in six of 10 patients after DCC but not after TAP ($p < 0.01$). The arrhythmias were benign (frequent, multifocal, or coupled) ventricular premature beats in four patients and transient second degree heart block in two patients. One patient developed a 10 s episode of non-sustained ventricular tachycardia that was treated with a short course of intravenous lidocaine. One patient developed complete heart block and prolonged hypotension that was successfully treated with cardiopulmonary resuscitation and atropine. The serum digoxin concentration was subsequently found to be slightly raised (beyond the therapeutic range) to 2.3 $\mu\text{g/dl}$ in this patient.

Discussion

The efficacy of rapid atrial pacing to end atrial flutter is well established. An analysis of the major clinical trials involving transvenous pacing shows a cumulative success rate of 82% (range 55%–100%).¹⁴ In the immediate period after open heart surgery, rapid atrial pacing through wire electrodes implanted on the atrial epicardium is considered to be the treatment of choice, with a reported efficacy of 90%–100%.¹⁵ Although highly successful, direct atrial stimulation is limited by its invasive nature, which requires sterile precautions, fluoroscopy, cardiac catheterisation, and considerable operator expertise. Transoesophageal atrial pacing is a simple and non-invasive technique with efficacy similar to transvenous pacing. The use of an oesophageal electrode to pace the heart was first reported by Zoll in 1952, who used the electrode for ventricular pacing.¹⁶ Since then, several clinical trials have investigated TAP as a technique to end atrial arrhythmias. Table 3

Table 2 Comparability of clinical characteristics

	TAP	DCC	p Value
Age (mean (SD))	69.9 (7.4)	71.0 (7.6)	0.86
Sex (M/F)	7/4	7/3	0.35
Flutter rate (mean (SD))	301.8 (8.4)	284.5 (37.5)	0.13
ASCAD	9 of 11	9 of 10	0.83
LAD (mm, mean (SD))	45.2 (5.2)	42.7 (7.3)	0.43
Digoxin	11 of 11	10 of 10	—
Class IA antiarrhythmic drugs	10 of 11	9 of 10	0.91
Duration of atrial flutter (days, mean (SD))	7.2 (4.8)	5.3 (3.9)	0.09

Table 3 Analysis of previous clinical trials

Investigator	Study size	arrhythmia to NSR	Conversion AF → NSR	Transient AF	Persistent AF alter rhythm	Failure to success (%)	Overall
Gallagher <i>et al</i> ⁶	38	SVT	33	4	0	1	97(37/38)
Chung <i>et al</i> ⁷	26	AFI	17	5	0	4	85(22/26)
Crawford <i>et al</i> ⁸	39	AFI	15	17	5	2	82(32/39)
Falk and Werner ¹¹	14	AFI	1	5	4	4	43(6/14)
Total							83 (97/117)

NSR, normal sinus rhythm; AFI, atrial flutter; AF, atrial fibrillation; SVT, supraventricular tachycardia.

reviews the four major trials, and a cumulative success rate of 83% (97/117) is reported. The best results are reported by Gallagher *et al*; however, no patients with atrial flutter were included in this trial.⁶ In the only previous study to use TAP for atrial flutter, Falk *et al* report an efficacy of 43% with most patients developing transient atrial fibrillation.¹¹ Overall in these studies, 27% (range 11%–83%) of patients developed a transient period of atrial fibrillation. This compares favourably with our results in which atrial flutter was ended in 72% (8/11) with 75% (6/8) developing a transient period of atrial fibrillation. Conversion to atrial fibrillation may also be of benefit. In our study group, atrial fibrillation was always accompanied by a reduction in ventricular rate and subsequent conversion to normal sinus rhythm. Persistent atrial fibrillation, as reported in previous clinical trials of rapid atrial pacing, is generally better tolerated than atrial flutter and is more responsive to medical cardioversion.^{17,18}

Gallagher *et al* performed strength-duration curves that showed that oesophageal current threshold decreased progressively as pulse duration was increased to the limit of the stimulator (9.9 ms).⁶ In our clinical trial, we chose to maintain pulse width at the stimulator limit of 10 ms. The experience of Chung *et al*, who used pulse widths up to 25 ms, suggest, however, that increases beyond 10 ms may improve the rates of ending atrial flutter.⁷ Theoretically, increased pulse widths might result in higher rates of inadvertent ventricular capture. This event has been described only rarely, however, and was not found in the present study. A sensation of transient epigastric burning, similar to our findings, has been reported to accompany TAP in a high percentage of cases. With a silicone insulated permanent bipolar pacing lead, Chung *et al* reported that 23% (9/39) of patients require intravenous sedation during TAP.⁷ No patients undergoing TAP in our study required intravenous sedation and most patients agreed that they would undergo the procedure again under similar circumstances. An advantage of TAP was that intravenous sedation was found to be unnecessary whereas DCC requires light anaesthesia and the presence of a trained anaesthesiologist.

Arrhythmias after cardioversion in digitalised patients undergoing DCC have been previously reported to be raised.¹⁹ Our results support these findings. Although most of the arrhythmias found were of a benign nature, 20% (2/10) of patients in the DCC group experienced a potentially life threatening arrhythmia. Arrhythmias probably result from digitalis cardiotoxicity.²⁰ Subsequent treat-

ment of these arrhythmias should avoid additional direct current shocks as ventricular fibrillation may result.

Although several potential mechanisms for atrial flutter have been described, most clinical and experimental evidence supports a leading circle model of obstacle reentry.^{21–23} This model uses the concept of a fully excitable gap that exists between the crest of the circulating wavefront and its tail of refractory myocardium and explains the reproducible end of atrial flutter with entrainment and rapid atrial pacing. The end of reentrant tachycardias by appropriately timed pacing stimuli occurs due to invasion of the reentrant circuit by the externally induced impulses. The pacing stimuli enter the circuit at the excitable gap, thereby rendering this tissue refractory to the circulating wavefront. Also, pacing stimuli may occur during the atrial vulnerable period inducing an atrial R on T phenomenon and fibrillation. Such a process may account for the frequency of transient atrial fibrillation found in our study. Class IA antiarrhythmic agents greatly decrease myocardial conduction velocity and to a lesser degree prolong the myocardial refractory period.²⁴ The net effect in atrial flutter is to prolong the excitable gap. This may increase the efficacy of rapid atrial pacing by facilitating invasion of the pacing stimuli into a widened excitable gap,²⁵ and probably has contributed to the favourable results found in this study.

Our results show that TAP with a pill electrode is safe, well tolerated, and is as efficient as DCC for refractory atrial flutter. Class IA antiarrhythmic drugs probably facilitate TAP and should be considered adjunctive agents to the technique. Transoesophageal atrial pacing is especially well suited to patients taking digoxin or when digitalis toxicity is a consideration. Transoesophageal atrial pacing may also be considered in cases where DCC is not readily available or when light anaesthesia is contraindicated. The technique may also be combined with transoesophageal electrocardiography and used for diagnostic purposes in patients with an indeterminate rhythm on a surface electrocardiogram.

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