

Orthogonal electrical cardioversion in atrial fibrillation refractory to biphasic shocks: a case series

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Background

Biphasic waveform shock has been established as the standard method for cardioversion of atrial fibrillation (AF). Depending on various factors, standard electrical cardioversion for AF may be unsuccessful in some cases, even with biphasic shocks.

Case summary

We report the safety and efficacy of orthogonal electrical cardioversion (OECV) as an alternative in patients with paroxysmal AF refractory to standard biphasic electrical cardioversion after up to three subsequent shocks of increasing energy and/or two or three initial shocks with maximum energy of 200-Joules. Shocks were delivered with two external defibrillators via two sets of adhesive electrode pads to apply two perpendicular electrical vectors in a simultaneous-sequential mode in antero-lateral and antero-posterior configuration. Five patients, mean age 54.4 ± 11 , three with hypertensive heart disease and a body mass index $27.2 \pm 2 \text{ kg/m}^2$. All individual mean impedance before OECV was $79 \pm 5 \Omega$ with a mean peak current applied of $22 \pm 4.5 \text{ A}$. Restoration of sinus rhythm with OECV was achieved acutely and sustained in all five patients. No patients developed haemodynamic instability or thromboembolic events.

Discussion

Double simultaneous shocks in an orthogonal configuration could theoretically decrease the defibrillation threshold through the ability of sequential pulses applying a more efficient and uniform current density. OECV using lower/medium energy may be another useful rescue strategy in AF refractory to standard biphasic shocks.

Keywords

Case series • Biphasic waveform shock • Double simultaneous shocks • Electrical cardioversion • High-energy cardioversion • Refractory atrial fibrillation • Transthoracic impedance

Introduction

Standard direct-current electrical cardioversion (ECV) using different types of waveforms is associated with variable success rate to convert atrial fibrillation (AF) to sinus rhythm (SR). About 88% of patients treated with an initial 100-Joules (J) biphasic shock were

cardioverted to SR, compared with 70% of those treated with an initial 200-J monophasic shock.^{1,2} Many variables have been identified that influence the success rate; such as AF duration, monophasic vs. biphasic shocks, use of anti-arrhythmic pre-treatment, and notably various factors that influence the transthoracic impedance (TTI).^{3,4} In patients in whom conventional ECV fails,

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Learning points

- Although biphasic shocks have higher chance to achieve cardioversion with less energy and less shocks, is unsuccessful in 4–11% in the real world.
- Successful cardioversion depends on delivery a sufficient electrical current to the heart, this is determined by the selected energy and by the transthoracic impedance.
- The orthogonal electrical cardioversion creates two distinct current pathways to deliver higher energy, increasing the amount of muscle mass defibrillated.

various strategies have been proposed: (i) initiate or scale to higher-energy shocks⁵; (ii) change to the anterior–posterior position trying to get a stronger shock field^{1,6}; and (iii) deliver double high-energy shocks.^{7–11} Although biphasic waveform shocks have higher chance to achieve cardioversion in the first and/or after a sequence of attempts with less energy and less shocks, this standard ECV is unsuccessful in 4–11% in the real world.^{2,12,13} Derived of our previous experience,¹⁰ we report a preliminary case series of the efficacy and safety with a technique we call orthogonal electrical cardioversion (OECV) as an alternative for AF refractory to standard biphasic transthoracic shocks.

Timeline

Case series

Patients enrolled were refractory to standard biphasic waveform ECV after up to three subsequent shocks of increasing energy and/or two or three initial shocks with maximum energy of 200-J using hand-held paddles (HeartStart MRx, M3535A Phillips, Andover, MA, USA) in the antero-lateral position.

Patients

Five consecutive patients were enrolled open and non-randomized, with a clear history of symptomatic recent-onset or recurrent paroxysmal AF. Patients were enrolled after being made aware of the option to undergo rate control or another attempt with the OECV technique. Following written informed consent, four patients underwent OECV within 12–24 h after failed standard ECV and one patient

Date	Pre-electrical cardioversion (ECV) (type/duration)	Standard ECV	Post-standard ECV	Orthogonal ECV	Follow-up
September 2017 Case 1	Recent-onset paroxysmal atrial fibrillation (AF) (14 h)	Unsuccessful (3 shocks)	Enoxaparin Transthoracic echo (TTE)	Successful	Sustained sinus rhythm (SR) 29 months Ribaroxaban CHA ₂ DS ₂ -VASc 1 HAS-BLED 1
March 2018 Case 2	Recent-onset paroxysmal AF (12 h)	Unsuccessful IV amiodarone ↓ Unsuccessful (2 shocks)	Enoxaparin TTE	Successful (2 double shocks)	AF recurrence 6 months later CHA ₂ DS ₂ -VASc 0
May 2018 Case 3	Recent-onset paroxysmal AF (6 h)	Unsuccessful (3 shocks)	Enoxaparin TTE	Successful	Sustained SR 25 months CHA ₂ DS ₂ -VASc 0
June 2019 Case 4	Recurrent persistent short-lasting AF (24 days)	Unsuccessful atrial flutter (AFL) (3 shocks) ↓ AF (1 shock)	Rivaroxaban (3 weeks) ↓ Transoesophageal echo (TOE)	Successful	Sustained SR 24 months Rivaroxaban CHA ₂ DS ₂ -VASc 1 HAS-BLED 1
February 2020 Case 5	Previous radiofrequency catheter ablation (2 years before) ↓ Recurrent paroxysmal AF (26 h)	Unsuccessful (3 shocks)	Enoxaparin TTE	Successful	AF recurrence 2 months later Rivaroxaban CHA ₂ DS ₂ -VASc 2 HAS-BLED 2

with short-lasting persistent AF/flutter (AFL) was prospectively scheduled. All patients underwent transthoracic echocardiogram before the procedure and, the patient with short-lasting persistent AF/AFL was anticoagulated during 3 weeks and, transoesophageal echocardiography was made 12 h before OECV. Patient characteristics are summarized in *Table 1*.

Defibrillators and cardioversion

The OECV method used two simultaneous defibrillators (same model as for standard cardioversion), each one delivers up to 200-J of direct-current energy of biphasic truncated exponential waveform (adjusted as a function of patient impedance). OECV shocks were delivered via adhesive electrode pads with a conductor surface area of 75 cm² (M3713A Multifunctional Adult Plus, Phillips, Andover, MA, USA) to apply two perpendicular electrical vectors in a sequential and synchronized mode in antero-lateral (high right infraclavicular and left mid-axillary line) and antero-posterior (low right parasternal and left infra-scapular and spine) position using a cathodal configuration (*Figure 1*).

Synchronization was made using in both defibrillators the same II electrocardiogram (ECG) leads and gain with a minimum amplitude of 0.50 mV. The energy delivery of both defibrillators was applied by a single operator that push simultaneously the shock button of each defibrillator as a single shock ($J \times 2$). In case of unsuccessful first orthogonal shock, a subsequent shock was delivered at least 3-min intervals between the next energy level.

Successful OECV was defined as a return to SR immediately after the shock and its maintenance for at least ≥ 60 s. After 2–6 h, levels of cardiac troponin I (cTnI), serum creatine kinase (CK), and MB fraction (CK-MB) were analysed.

Results

The mean age was 54.4 ± 11 years (median, 58) with body mass index (BMI) 27.2 ± 2 kg/m², (range 24.5–30), all were men. There was

hypertensive heart disease in three. The mean left ventricular ejection fraction was $58 \pm 3\%$ estimated by echocardiography and the left atrial antero-posterior diameter 38 ± 4 mm. Two patients were

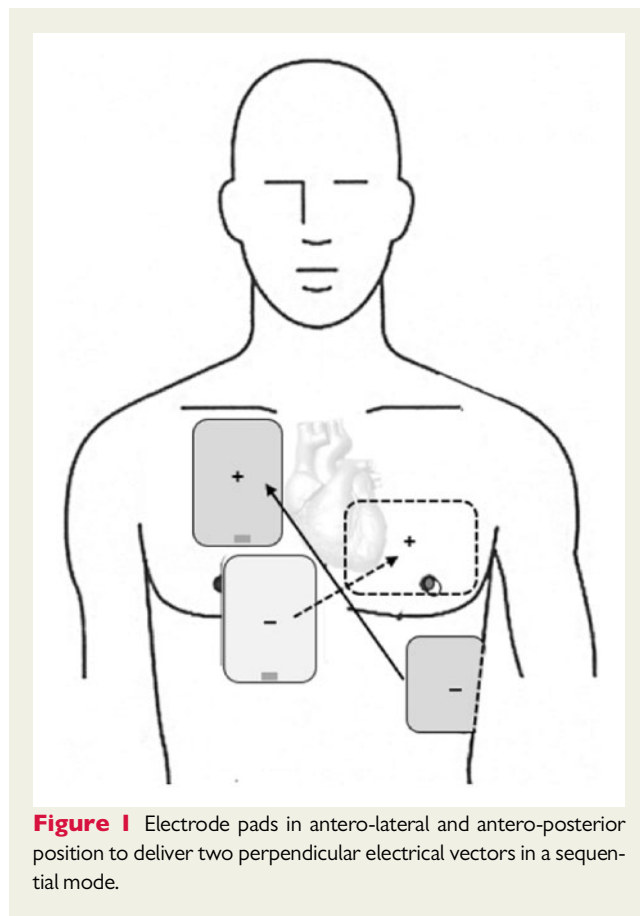


Figure 1 Electrode pads in antero-lateral and antero-posterior position to deliver two perpendicular electrical vectors in a sequential mode.

Table 1 Patients characteristic

Patient	Age (years)	BMI (kg/m ²)	Type of AF	Duration of AF	Previous AAD	Unsuccessful standard ECV	TTI (Ω)	Current (A)	Successful orthogonal ECV
1	61	22.2	Recent onset paroxysmal HHD	14 h		150-J, 200-J, 200-J	81	22.2	50-J \times 2
2	58	26.4	Recent onset paroxysmal Normal heart	12 h		Unsuccessful IV Amiodarone \rightarrow 200-J, 200-J	81	18.6	100-J \times 2 and 150-J \times 2
3	42	21.1	Recent onset paroxysmal Normal Heart	6 h		150-J, 200-J, 200-J	73	27.3	50-J \times 2
4	44	24.4	Recurrent short-lasting persistent HHD	24 days	Propafenone 450 mg/day PO	(AFL)100-J, 200-J, 200-J, (AF) 200-J	84	17.1	150-J \times 2
5	67	28.2	Recurrent paroxysmal HHD	26 h	Flecainide 200 mg/day PO	100-J, 150-J, 200-J	76	26.3	150-J \times 2
Mean \pm SD	54.4 \pm 11	24.5 \pm 3					79 \pm 4.4	22.3 \pm 4.5	

A, ampere; AAD, at antiarrhythmic drugs; AF, atrial fibrillation; AFL, atrial flutter; BMI, body mass index; ECV, electrical cardioversion; HHD, hypertensive heart disease; TTI, transthoracic impedance; Ω , ohms.

taking antiarrhythmic drugs and one failed to an attempt of pharmacological cardioversion before standard ECV. On the ECG, fine fibrillatory activity was present in three and only one had AF/typical AFL. Duration of current AF episode before standard ECV was between 6 and 26 h in four and 24 days in one patient and, the time for OECV after failed standard ECV was 3–21 h and 2 h, respectively.

Restoration of SR was achieved acutely and sustained in all five patients who received an orthogonal shock. On the first OECV attempt, four patients were treated successfully (80%); due to failure of the first attempt, one patient required a subsequent OECV successful shock. All individual mean impedance from standard ECV was $79 \pm 5 \Omega$ (range 73–84, median 81) and mean peak current $22 \pm 4.5 \text{ A}$ (range 17–26, median 22).

After OECV, frequent atrial premature beats occurred in two patients and received treatment with a single bolus of intravenous amiodarone to prevent relapse in AF. No patients developed haemodynamic instability, significant bradyarrhythmias, or thromboembolic events after the procedure and/or during follow-up. Transient ST-T segment elevation was not observed. cTnl remained undetectable ($<0.4 \text{ ng/mL}$) in all patients, CK levels were above upper reference limits at 6 h after OECV in one patient, but mean values of CK-MB and CK-MB/CK ratio did not reach diagnostic levels for myocardial injury in any patient. No patient had chest discomfort post-OECV and usual mild skin irritation was limited to outer ring of the adhesive electrode pads in one patient. All five successful cases were discharged in stable SR with conventional oral doses of class 1C or III agents and/or elective catheter ablation was proposed. Long-term oral anticoagulant therapy was administered on an individual basis (CHA₂DS₂-VASc and HAS-BLED scores). During a mean follow-up of 18.6 ± 11 months, two patients had AF recurrence 6 and 2 months after OECV.

Discussion

This case series demonstrated that OECV with low or median-energy is an effective and safe alternative strategy to restore SR for AF refractory to standard biphasic shocks. Depending on various factors, standard ECV for AF may be unsuccessful in some cases.^{12,13} The relative importance of these variables have been extensively evaluated and, is the electrical current flow the most important.^{3,4} Successful ECV depends on delivery a sufficient electrical current to the heart; this current flow is determined by the selected energy shock and notably by the TTI. If this is high, a low energy selected may generate inadequate current to achieve cardioversion. It has been demonstrated that this can be overcome with the use of an impedance-compensated biphasic waveforms in terms of greater success with less energy and less shocks. Then, biphasic waveform shock has been established as the standard method for cardioverting AF. In this limited number of cases, there was a weak correlation between BMI and TTI because patients were in the overweight range if compared to other reports with patients in the obesity range consistent with high or very-high TTI.³ In studies that evaluated the importance of impedance in determining the success rate, authors have found a wide range of values, mean $78.1 \pm 19.4 \Omega$ without difference between hand-held paddles vs. adhesive pad electrodes ($79 \pm 15 \Omega$ and $77 \pm 23 \Omega$ respectively) and, considered 'high' impedance, mean

$89 \pm 16 \Omega$ (range 70–150).^{4,14} In our cases, all individual mean impedance from hand-held paddles was in the averaged range or slightly higher, $79 \pm 5 \Omega$ (range 73–84, median 81) which led to deliver a low peak current, mean, $22 \pm 4.5 \text{ A}$ (range 17–26), an actual insufficient current flow if we consider the results of Kerber *et al.*³ who reported the relationships between peak current and shock success of 42% with (22–25 A), 56% (26–29 A), and the highest success rate 70% (30–33 A) for all shocks in AF using an automated impedance-based defibrillator. Minimizing TTI during ECV increases transmucosal current and the chance of delivering a successful shock. It is well known that firm force applied to defibrillator paddles is a way to decrease the TTI.^{4,15} Despite having used hand-held paddles with a LED indicator which ensures the patient contact and adjust paddle pressure; in our patients, we cannot entirely rule out a suboptimal pressure force.

Derived from canine models, first human studies on internal epicardial defibrillation protocols and using sequential pulses utilized substantially lower current and energy to defibrillate than does the single-pulse method, this was due at least in part to the changing orientation of the electrical vector during multiple pulse shocks.¹⁶ The first report of double sequential transthoracic shocks for refractory ventricular fibrillation (VF) (7–20 single shocks) using two defibrillators was a case series of five patients, all were successfully defibrillated.¹⁷

In the case of AF, it is well accepted that failure of ECV by standard monophasic or even biphasic shocks may be due to failure of delivery of enough defibrillating energy rather than to the true refractoriness of AF. Then for ECV to be successful, a critical muscle mass of the appropriate chambers must be defibrillated. According to Lerman and Deale,¹⁸ during transthoracic defibrillation in humans, only 4% of the transthoracic current actually traverses the heart and the remaining 96% was shunted by the thoracic cage and the lungs. The method of double transthoracic shocks was used also for refractory AF in order to create two distinct current pathways to deliver higher energy. Two set of electrodes in different positions would substantially increase the amount of muscle mass defibrillated. Bjerregaard *et al.*⁷ reported the first prospective study of the efficacy and safety of double transthoracic monophasic shocks in 15 patients with chronic refractory AF and restored SR in 67% of patients. Additionally, confirmed that TTI decreases with subsequent shocks and could have played a role in the success of the double shocks. Subsequent reports confirmed that the application of synchronized higher energy shocks was an alternative approach in AF refractory to standard ECV energies.^{8–11} The success rate achieved with double transthoracic high-energy shocks (720-J total dose) was 74–90% in chronic AF.^{7–11} Even when repeated in the same session, the double shocks were not associated with detrimental effects on the myocardium function compared to the 360-J shocks used during standard ECV.^{7–11} These pioneering studies reported patients essentially with chronic AF and obesity with high TTI, failure to monophasic shocks and subsequent success with high-energy double shocks. Therefore, the main differences with our case series were patients with paroxysmal AF, overweight (but not obese) with an averaged range TTI, failure to biphasic shocks and subsequent success with low or medium energy double shocks (100-J to 300-J). The potential mechanism by which OECV is associated with higher success rates has been speculative. It is probably a combination of three interacting factors: energy, perpendicular electrical vectors, and duration of the shock. Analogous to VF

defibrillation model, the orthogonal configuration could theoretically decrease the defibrillation threshold through the ability of sequential pulses applying a more efficient and uniform current density; changing the directional electrical vector during sequential shocks might facilitate cardioversion, since cardiac fibres and myocytes have directional sensitivity to electrical field stimulation and, with the increase in the duration of shock allows for depolarization of missed cells that continue to propagate disorganized rhythms and thus extinguishing the re-entrant circuits that sustain fibrillation.^{19,20} Additionally, it has been shown that the larger electrodes surface area reduces the overall TTI,⁴ then, the net result may be a wider current field encompassing much left atrial mass, thereby terminating fibrillation.

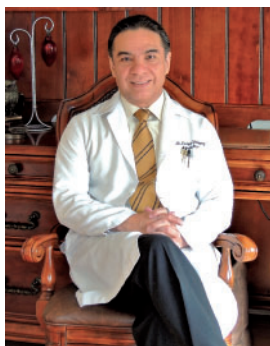
Conclusions

OECV using lower/medium energy may be a useful rescue strategy in paroxysmal or short-lasting AF refractory to standard biphasic shocks protocol. Success will have to be supported by a larger number of patients and could be tested in refractory long-lasting or chronic AF.

Study limitations

This is a preliminary report that included few patients. The initial energy selection was set at the discretion of the physician without an energy escalation protocol.

Lead author biography



Dr Enrique Velázquez-Rodríguez graduated Universidad Nacional Autónoma de México School of Medicine. Cardiologist from Hospital de Cardiología Centro Médico Nacional Siglo XXI, I.M.S.S. Fellow in Interventional Electrophysiology at Hôpital Jean Rostand, Ivry-Sur-Seine, France.

Supplementary material

Supplementary material is available at *European Heart Journal - Case Reports* online.

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Slide sets: A fully edited slide set detailing this case and suitable for local presentation is available online as [Supplementary data](#).

Consent: The author/s confirm that written consent for submission and publication of this case report including image(s) and

associated text has been obtained from the patient in line with COPE guidance.

Conflict of interest: none declared.

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