

# Cardioversion Efficacy Using Pulsed Biphasic or Biphasic Truncated Exponential Waveforms: A Randomized Clinical Trial

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**Background**—Several different defibrillators are currently used for cardioversion and defibrillation of cardiac arrhythmias. The efficacy of a novel pulsed biphasic (PB) waveform has not been compared to other biphasic waveforms. Accordingly, this study aims to compare the efficacy and safety of PB shocks with biphasic truncated exponential (BTE) shocks in patients undergoing cardioversion of atrial fibrillation or -flutter.

**Methods and Results**—This prospective, randomized study included patients admitted for elective direct current cardioversion. Patients were randomized to receive cardioversion using either PB or BTE shocks. We used escalating shocks until sinus rhythm was obtained or to a maximum of 4 shocks. Patients randomized to PB shocks received 90, 120, 150, and 200 J and patients randomized to BTE shocks received 100, 150, 200, and 250 J, as recommended by the manufacturers. In total, 69 patients (51%) received PB shocks and 65 patients (49%) BTE shocks. Successful cardioversion, defined as sinus rhythm 4 hours after cardioversion, was achieved in 43 patients (62%) using PB shocks and in 56 patients (86%) using BTE shocks; ratio 1.4 (95% CI 1.1–1.7) ( $P=0.002$ ). There was no difference in safety (ie, myocardial injury judged by changes in high-sensitive troponin I levels; ratio 1.1) (95% CI 1.0–1.3),  $P=0.15$ . The study was terminated prematurely because of an adverse event.

**Conclusions**—Cardioversion using a BTE waveform was more effective when compared with a PB waveform. There was no difference in safety between the 2 waveforms, as judged by changes in troponin I levels.

**Clinical Trial Registration**—URL: <http://www.clinicaltrials.gov>. Unique identifier: NCT02317029. (*J Am Heart Assoc.* 2017;6:e004853. DOI: 10.1161/JAHA.116.004853.)

**Key Words:** atrial fibrillation • biphasic waveforms • cardioversion

**A**trial fibrillation (AF) is the most common cardiac arrhythmia and affects millions of people worldwide.<sup>1</sup> To reduce symptoms and prevent disease progression, direct

current cardioversion is a widely used procedure for patients with AF.<sup>2</sup> During the past decades, biphasic waveforms have proven superior to monophasic waveforms for cardioversion of supraventricular tachycardia in several randomized studies.<sup>3–6</sup> In these studies, more patients were restored to sinus rhythm when receiving biphasic shocks compared with monophasic shocks, using less total delivered energy. Currently, several different biphasic waveforms are available in commercial defibrillators.

Recently, a new pulsed biphasic (PB) waveform was approved for direct current cardioversion and defibrillation.<sup>7</sup> This waveform delivers a chopped modulation of a biphasic truncated exponential (BTE) waveform, where current is rapidly and repeatedly turned on and off. In a nonrandomized clinical study, this PB waveform was found to be more effective in cardioversion of AF or atrial flutter compared with a monophasic waveform.<sup>8</sup> The PB waveform is designed to deliver a high peak and average current at low energy levels,<sup>9,10</sup> and it is hypothesized that the waveform can deliver high shock efficacy at low energy levels.<sup>7,11</sup>

To date, there are no clinical data on the efficacy of the impedance-compensated (ie, adjusted to patient's chest

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Accompanying Tables S1 and S2 are available at <http://jaha.ahajournals.org/content/6/3/e004853/DC1/embed/inline-supplementary-material-1.pdf>

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impedance) PB waveform, which is currently in use for direct current cardioversion and defibrillation. Lately, international guidelines have identified an important knowledge gap on using the PB waveform, and state that clinical data are warranted.<sup>12</sup> Because the PB waveform has never been compared to other biphasic waveforms in a randomized clinical study, we accordingly aimed to compare the cardioversion efficacy and safety of a PB waveform with a BTE waveform.

## Methods

### Study Design and Setting

We conducted a prospective, randomized study using a 2×2 factorial design. The study randomized patients to cardioversion using either PB or BTE shocks and investigated the use of 100% oxygen versus room air during the cardioversion procedure. The study was conducted at the Regional Hospital of Randers, Denmark, in an outpatient clinic performing elective day case cardioversions of patients with AF or atrial flutter.

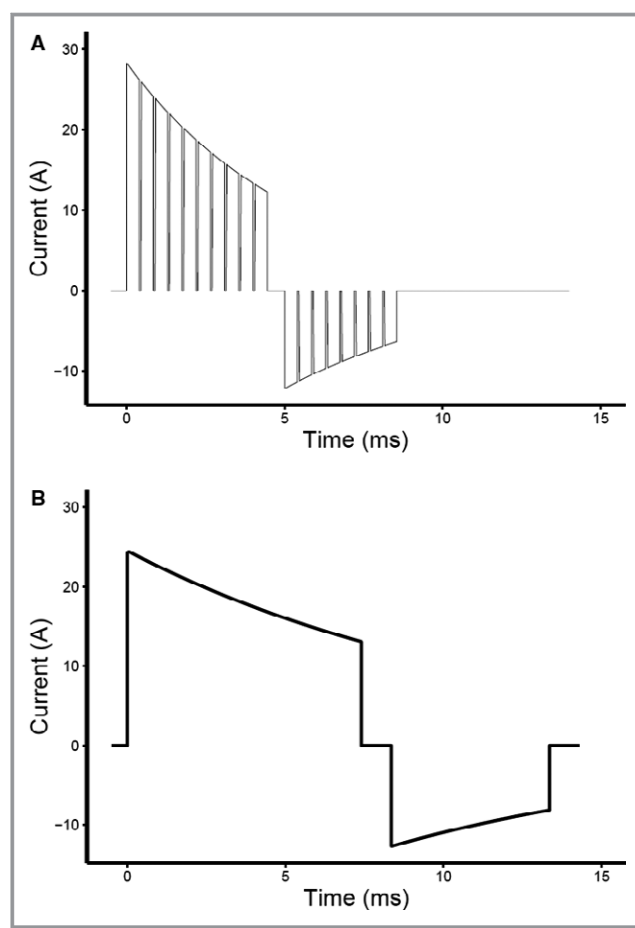
### Intervention

Patients were randomized to receive cardioversion using either PB shocks (Multipulse Biowave<sup>®</sup>, Schiller Defigard 5000, Schiller AG, Baar, Switzerland) or BTE shocks (LIFEPAK 20, Medtronic/Physio-Control Inc., Redmond, WA). Both waveforms use impedance compensation, where the patient's impedance is measured by a sensing pulse prior to shock delivery. In addition, the PB waveform uses the impedance to calculate an appropriate pulse-to-pause ratio. Diagrams of the waveforms are presented in Figure 1.

Patients were randomized using simple randomization with random numbers from 1 to 4 in sealed envelopes. Before cardioversion, the envelope was opened, assigning patients to 1 of the 4 treatment groups: (1) PB shocks and 100% oxygen, (2) PB shocks and room air, (3) BTE shocks and 100% oxygen, or (4) BTE shocks and room air.

### Study Population and Ethics

All patients admitted for elective cardioversion of AF or atrial flutter were eligible for inclusion. Patients were included at an elective visit 1 to 2 days before cardioversion. The exclusion criteria were age <18 years, pregnancy, untreated hyperthyroidism, or an oxygen saturation <92% and supraventricular arrhythmias other than AF or atrial flutter. All patients were required to be adequately anticoagulated or alternatively have undergone a recent transesophageal echocardiography documenting the absence of intracardiac thrombi.<sup>13</sup>



**Figure 1.** Biphasic waveforms. A, Pulsed biphasic waveform. B, Biphasic truncated exponential waveform. The figure illustrates shock delivery in milliseconds (ms) against current in ampere (A). For comparison, both shocks are illustrated at 150 J with an impedance of 80  $\Omega$ .

Information on patient characteristics was obtained at the precardioversion check including the patient's height, weight, blood pressure, heart rate, oxygen saturation (on room air), and a 12-lead ECG. Symptoms were assessed according to the European Heart Rhythm Association score of AF-related symptoms.<sup>13</sup> All data on medications and comorbidities were retrieved from the patient's medical records corresponding to the day before cardioversion.

Oral and written informed consent was obtained from all patients at the precardioversion visit. The study was conducted in accordance with national requirements and the principles of the Declaration of Helsinki. The study was approved by The National Committee on Health Research Ethics (no. 1-10-72-150-13) and the Danish Data Protection Agency (no. 1-16-02-425-13).

### End Points

The primary end point was successful cardioversion, defined as sinus rhythm 4 hours after cardioversion. Secondary end points

included sinus rhythm 1- and 30 minutes after cardioversion. The safety of the 2 defibrillators was evaluated by measuring high-sensitive cardiac troponin I (Hs-cTnI) before and 4 hours after cardioversion. Complications, in terms of cardioversion-induced arrhythmias, were further assessed including cases of ventricular tachyarrhythmia, short-duration asystole <20 s, and transient bradycardia <45 min<sup>-1</sup>. Data were obtained from ECG recordings and telemetric surveillance. Furthermore, any other complications including skin burns were noted in the patient's journal by the treating nurse.

## Cardioversion Protocol

Cardioversion shocks were provided until sinus rhythm was restored or to a maximum of 4 shocks. The patients randomized to PB shocks received 90, 120, 150, and 200 J, and the patients randomized to BTE shocks received 100, 150, 200, and 250 J. We used these escalating shock protocols based on manufacturer's recommended settings.

Anesthesia was provided in a standardized fashion to patients using 1 mg intravenous propofol per kilogram body weight to a maximum dose of patient's height in centimeters minus 100 cm. Subsequent boluses of 20 mg were administered as required. During the procedure, patients were treated with either oxygen or room air to maintain oxygen saturations of 94% to 98%.

We used the defibrillator-specific self-adhesive wet polymer gel pads. All shocks were delivered unblinded using an anterior–posterior pad position.<sup>14</sup> The anterior pad was applied to the left of the sternum with the pad centrum at third intercostal space. The posterior pad was placed with the pad edge laterally to the spinal column on the lower part of the scapula. The defibrillators were switched to “R” wave synchronized mode.

One minute after last shock delivery and after 30 minutes, the cardiac rhythm was documented by obtaining a 12-lead ECG. After 4 hours with continuous cardiac telemetric surveillance, another 12-lead ECG was recorded.

## Blood Sampling and Biochemical Analysis

Blood samples were drawn from a venous catheter into lithium heparin tubes and centrifuged immediately at 344g for 15 minutes. High-sensitive cardiac troponin I (hs-cTnI) was analyzed in a DANAK ISO 15189 accredited laboratory using ARCHITECT STAT hs-cTnI assay (Abbott Laboratories, Abbott Park, IL). The coefficient of variation was maximum 10% at the limit of quantification (10 ng/L).

## Statistical Analysis

In this study, we assumed a 15% difference in efficacy (ie, the proportion of patients in sinus rhythm 4 hours after

cardioversion), corresponding to an efficacy of 95% for 1 of the waveforms, and 80% for the other waveform, as previously used.<sup>15</sup> To achieve a power of 80% to detect this difference (ie, to reject the null hypothesis of no difference between the waveforms), a sample size of 75 patients in each group was needed. Normally distributed data were expressed as mean±SD, non-normally distributed data were expressed as median (25- and 75-percentile), and categorical variables were expressed as numbers (percentages). We reported the primary and secondary end point as a ratio between treatment groups with 95% CIs. When comparing cardioversion success, we used the  $\chi^2$  test or Fisher's exact test. We separately analyzed patients with AF and atrial flutter, and patients receiving and not receiving amiodarone. To evaluate the hs-cTnI values and the assumptions behind the test, we used X-Y plots, Q-Q plots, and Bland–Altman plots. The Bland–Altman plots were performed separately for the 2 waveform groups using the hs-cTnI values before and after cardioversion. The assumptions were met on logarithm transformed data. Accordingly, the hs-cTnI values were transformed to the logarithmic scale, and differences were calculated. Subsequently, the differences on the logarithmic scale were transformed to the original scale, and consequently reported as a ratio of geometric means. The shock protocols were not completely identical, because of different available energy settings in each device, and the difference in success between the 2 waveforms was therefore further evaluated according to the energies used. Furthermore, we compared cardioversion success between patients treated with 100% oxygen and room air by binomial generalized linear models with a log link function including and excluding the additional intervention. Moreover, we tested for interaction between the 2 types of intervention. We used likelihood ratio tests for these models.

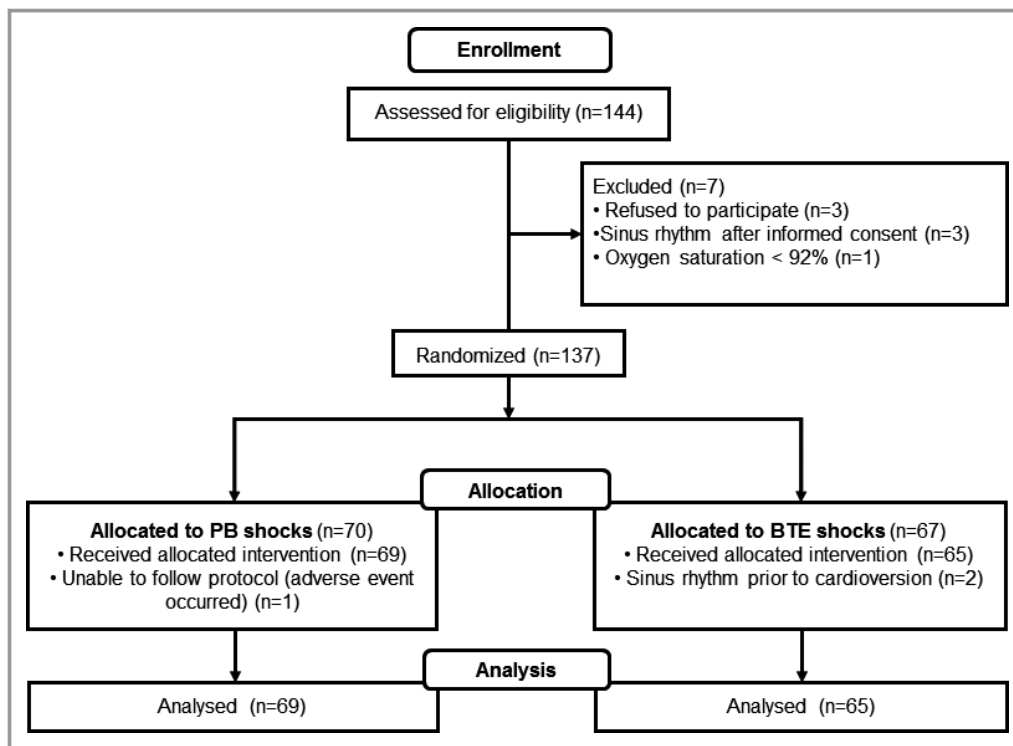
The graphical illustration was performed using Graph-Pad Prism version 6 and for statistical computing, we used R statistical software, version 3.1.1.<sup>16</sup>

## Results

### Patients

A total of 134 patients were enrolled between September 2013 and August 2014 (Figure 2). Of these, 69 patients (51%) were randomized to cardioversion using PB shocks, and 65 patients (49%) to BTE shocks.

Baseline characteristics of the 134 patients included are presented in Table 1. The 2 treatment groups were balanced on patient's demographics, comorbidities, cardiac medications, vital parameters, laboratory data, and AF-related symptoms, except that more patients in the BTE waveform group received amiodarone than patients in the PB waveform



**Figure 2.** The CONSORT flow diagram showing patient treatment allocation and exclusions. BTE indicates biphasic truncated exponential; CONSORT, Consolidated Standards of Reporting Trials; PB, pulsed biphasic.

group. In total, 35 (50.7%) of patients randomized to PB shocks received 100% oxygen, and 32 (49.2%) of patients randomized to BTE shocks received 100% oxygen.

### Shock Characteristics

In total, 192 PB shocks and 139 BTE shocks were delivered. The median (25- and 75-percentile) number of shocks delivered per patient was for the PB waveform 3 (1 and 4) and for the BTE waveform 2 (1 and 3). The corresponding median total energy delivered was for PB shocks 360 J (90 and 560 J) and for BTE shocks 250 J (100 and 450 J). The mean ( $\pm$ SD) transthoracic impedance at first shock was for PB shocks  $73 \pm 14 \Omega$  and for BTE shocks  $72 \pm 15 \Omega$ .

### End Points

The primary end point and secondary efficacy end points are presented in Table 2. The subgroup analyses of the primary end point are presented in Table 3 (patient's characteristics of the subgroups can be found in Tables S1 and S2).

The cumulative success rate at the different energy levels used is shown in Figure 3. As shocks were delivered at 150 and 200 J for both waveforms, we compared cardioversion success at these energies. For 150-J shocks, the PB waveform success rate was 26% and 40% for the

BTE waveform (ratio; 1.5, 95% CI 0.8–2.9,  $P=0.2$ ). For shocks at 200 J, the PB shock success rate was 30% and 44% for the BTE waveform (ratio: 1.5, 95% CI 0.7–3.0,  $P=0.3$ ). There was no statistical difference in demographic data among patients in whom cardioversion was attempted at 150 and 200 J (data not shown). Moreover, we tested for interaction between the cardioversion efficacy of the 2 waveforms and the 100% oxygen/room air intervention. The interaction between the interventions was not significant ( $P=0.3$ ) and, furthermore, there was no difference between 100% oxygen and room air on cardioversion efficacy either with ( $P=0.46$ ) or without ( $P=0.84$ ) adjustment for the waveform used.

### Defibrillator Safety

There was no difference in hs-cTnI change between PB and BTE shocks; ratio 1.1 (95% CI, 1.0–1.3,  $P=0.15$ ). The overall risk of any complication following a cardioversion shock was for the PB waveform 7 cases out of 192 shocks (4%) and for BTE waveform 4 cases out of 139 shocks (3%); ratio 1.3 (95% CI, 0.4–4.2,  $P=0.77$ ). Two patients (3%) treated with PB shocks developed ventricular tachyarrhythmia immediately after cardioversion compared to none when using BTE shocks (see below). Periods of short-duration asystole (all  $<20$  s) were reported for 1 patient in the PB group (1%) and 2

**Table 1.** Characteristics of the 134 Patients Included by Treatment Groups

Patient's Characteristics	PB Waveform	BTE Waveform
<b>Demographics</b>		
No. of patients	69	65
Age, y (mean±SD)	66±9	67±8
Male (%)	51 (74)	51 (78)
Atrial flutter	9 (13)	9 (14)
AF or -flutter duration in months, median (quartiles)	3 (2; 9)	5 (2; 24)
Prior cardioversions, median (range)	0 (0–5)	0 (0–6)
Prior pulmonary vein ablation, median (range)	0 (0–3)	0 (0–1)
<b>Comorbidities, %</b>		
Hypertension	51 (74)	51 (78)
Congestive heart failure	20 (29)	12 (19)
Valvular heart disease	3 (4)	7 (11)
Thyroid disease	0 (0)	2 (3)
Prior stroke/transient ischemic attack	6 (9)	4 (6)
Prior myocardial infarction	1 (1)	5 (8)
Ischemic heart disease	13 (19)	12 (18)
Hyperlipidemia	29 (42)	28 (43)
Chronic obstructive pulmonary disease	2 (3)	5 (8)
<b>Cardiac medication, %</b>		
Amiodarone	6 (9)	18 (28)
Digoxin	14 (19)	18 (28)
Flecainide	1 (1)	1 (2)
ACE/angiotensin-II blocker	44 (64)	40 (62)
β-Blocker	57 (83)	53 (82)
Calcium antagonist	16 (23)	20 (31)
<b>Vital parameters and laboratory data</b>		
Body mass index, kg/m <sup>2</sup>	29±6	30±6
Systolic blood pressure, mm Hg	136±17	135±21
Diastolic blood pressure, mm Hg	82±14	80±13
Heart rate before cardioversion, min <sup>-1</sup>	80±20	80±18
Estimated glomerular filtration rate	69±14	69±17

Continued

**Table 1.** Continued

Patient's Characteristics	PB Waveform	BTE Waveform
Hemoglobin, mmol/L	9.3±0.8	9.3±0.9
Thyroid-stimulating hormone (IU × 10 <sup>-3</sup> /L)	1.57 (1.00; 2.59)	1.67 (0.99; 2.49)
Total propofol dose, mg	113±43	107±33
<b>Patient's symptoms (EHRA score), %</b>		
I	31 (45)	26 (40)
II	31 (45)	29 (45)
III	7 (10)	10 (15)
IV	0 (0)	0 (0)

ACE indicates angiotensin-converting enzyme; AF, atrial fibrillation; BTE, biphasic truncated exponential; EHRA, European Heart Rhythm Association score of AF-related symptoms; PB, pulsed biphasic.

patients (3%) in the BTE group. Transient bradycardia (<45 min<sup>-1</sup>) was observed in 4 patients (6%) from the PB group and 2 patients (3%) from the BTE group. There were no observations of skin burns following cardioversion using either the pulsed or truncated exponential waveform during the study.

### Adverse Events

Because of a major adverse event, the study was terminated prematurely. The adverse event occurred in a 61-year-old male AF patient who was randomized to cardioversion using PB shocks. The patient had a history of hypertension and hypercholesterolemia, but without any history of structural heart disease or heart failure. The patient had a normal QT-interval, plasma potassium, and creatinine levels within normal range, and did not receive any antiarrhythmic medication. A synchronized cardioversion shock of 90 J was delivered, and immediately after the patient developed sustained polymorphic ventricular tachycardia (Figure 4). Three stacked shocks with the PB device did not result in successful defibrillation. After 8 minutes of advanced life support, including further repeated defibrillation attempts, the patient was switched to the BTE defibrillator and successfully defibrillated at first shock (300 J). After return of spontaneous circulation, the patient was transferred to an invasive cardiac center for acute angiography, showing no signs of coronary artery disease. The patient was treated with therapeutic hypothermia for 24 hours. Analysis of the rhythm strip printed by the defibrillator revealed that the intended synchronized cardioversion shock was delivered asynchronously (Figure 4).

Three months before this event, we experienced a case where a patient, after shock delivery, developed a short run of



**Table 2.** The Primary End Point and the Secondary Efficacy End Points on Successful Cardioversions, ie, the Proportion of Patients in Sinus Rhythm

Successful Cardioversions	PB Waveform	BTE Waveform	Ratio (95% CI)	P Value
Primary end point				
Sinus rhythm after 4 hours	43 (62)	56 (86)	1.4 (1.1–1.7)	0.002
Secondary end points				
Sinus rhythm after 1 minute	46 (67)	58 (89)	1.3 (1.1–1.6)	0.002
Sinus rhythm after 30 minutes	46 (67)	57 (88)	1.3 (1.1–1.6)	0.004

Data are numbers of successful cardioversions (%) and estimates are reported with their corresponding 95% CI. BTE indicates biphasic truncated exponential; PB, pulsed biphasic.

nonsustained ventricular tachycardia, which was rapidly converted with an additional shock. The rhythm strip revealed that a nonsynchronous shock had been administered. The physician who performed the cardioversion felt confident that the PB device was set to synchronized mode; however, the delivery of the asynchronous shock was at that time interpreted as caused by a human error.

Following these incidents, we became aware that the synchronization failure may have been attributable to an error in the PB device rather than human errors. Consequently, after the second case emerged, we tested the defibrillator's synchronization function in our animal laboratory, confirming that asynchronous shocks were delivered despite that the defibrillator was switched into synchronous mode.

The PB device was returned to the manufacturer for further analysis, confirming that an error in the device software caused the delivery of the asynchronous shock despite that the PB device was set in synchronous modus. All required reporting to national regulatory agencies and the manufacturer of the PB device was performed and subsequently a safety notice was published on the synchronization software failure.<sup>17</sup>

## Discussion

This is the first randomized clinical study comparing the efficacy of a PB waveform with a BTE waveform demonstrating a higher efficacy for BTE shocks compared with PB shocks in

cardioverting AF. There was no difference in safety (ie, myocardial injury measured by changes in troponin I levels).

For every fourth patient cardioverted with BTE shocks, 1 patient would have failed cardioversion if the PB waveform had been used. This substantial amount of failed cardioversions when using PB shocks may have profound clinical implications. The “failed” patients suffered longer time in arrhythmia, may have to be readmitted for another cardioversion attempt, possibly prescribed a concomitant antiarrhythmic drug, or treated with rate control therapy.

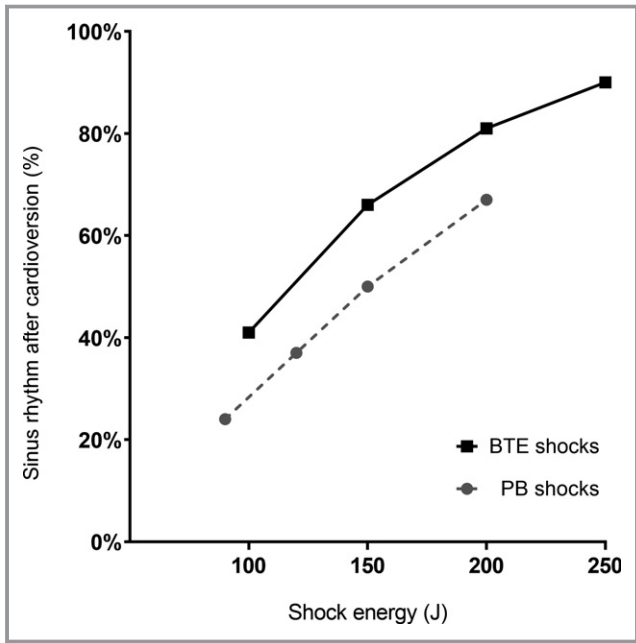
The impedance-compensated (ie, adjusted to differences in chest impedance) PB waveform, which is in clinical use, has not previously been compared to other waveforms. In cardioversion of atrial arrhythmias, a nonimpedance compensated PB waveform was more efficient than a monophasic waveform on the energy used to obtain sinus rhythm in patients with atrial arrhythmias.<sup>8</sup> One study on 104 out-of-hospital cardiac arrest patients with shockable rhythm compared a nonimpedance compensated version of the PB waveform to a BTE waveform.<sup>18</sup> The study reported similar defibrillation success rates for PB shocks (90.4%) and the BTE waveform (weighted average 91.8%).

Different versions of PB waveforms have been evaluated in animal studies using ventricular fibrillation pig models.<sup>19,20</sup> The studies found that the same energy levels were needed to terminate ventricular fibrillation using PB shocks compared to a rectilinear biphasic waveform,<sup>19</sup> and more energy when compared to a BTE waveform.<sup>20</sup> These findings are consistent

**Table 3.** Subgroup Analysis on the Primary End Point, ie, the Proportion of Patients in Sinus Rhythm After 4 Hours

	PB Waveform	BTE Waveform	Ratio (95% CI)	P Value
Sinus rhythm after 4 hours				
Atrial fibrillation patients (n=116)	35 (58)	47 (84)	1.4 (1.1–1.8)	0.002
Atrial flutter patients (n=18)	7 (77)	9 (100)	1.3 (0.9–1.9)	0.13
Patient receiving amiodarone (n=24)	2 (33)	16 (89)	2.7 (0.9–8.4)	0.05
Patients not receiving amiodarone (n=110)	40 (64)	40 (85)	1.4 (1.1–1.7)	0.01

Data are numbers of successful cardioversions (%) and estimates are reported with their corresponding 95% CI. BTE indicates biphasic truncated exponential; PB, pulsed biphasic.



**Figure 3.** The figure shows the energy in joules (J) delivered (90–250 J) against the cumulative cardioversion success of the 2 waveforms used. BTE indicates biphasic truncated exponential; PB, pulsed biphasic.

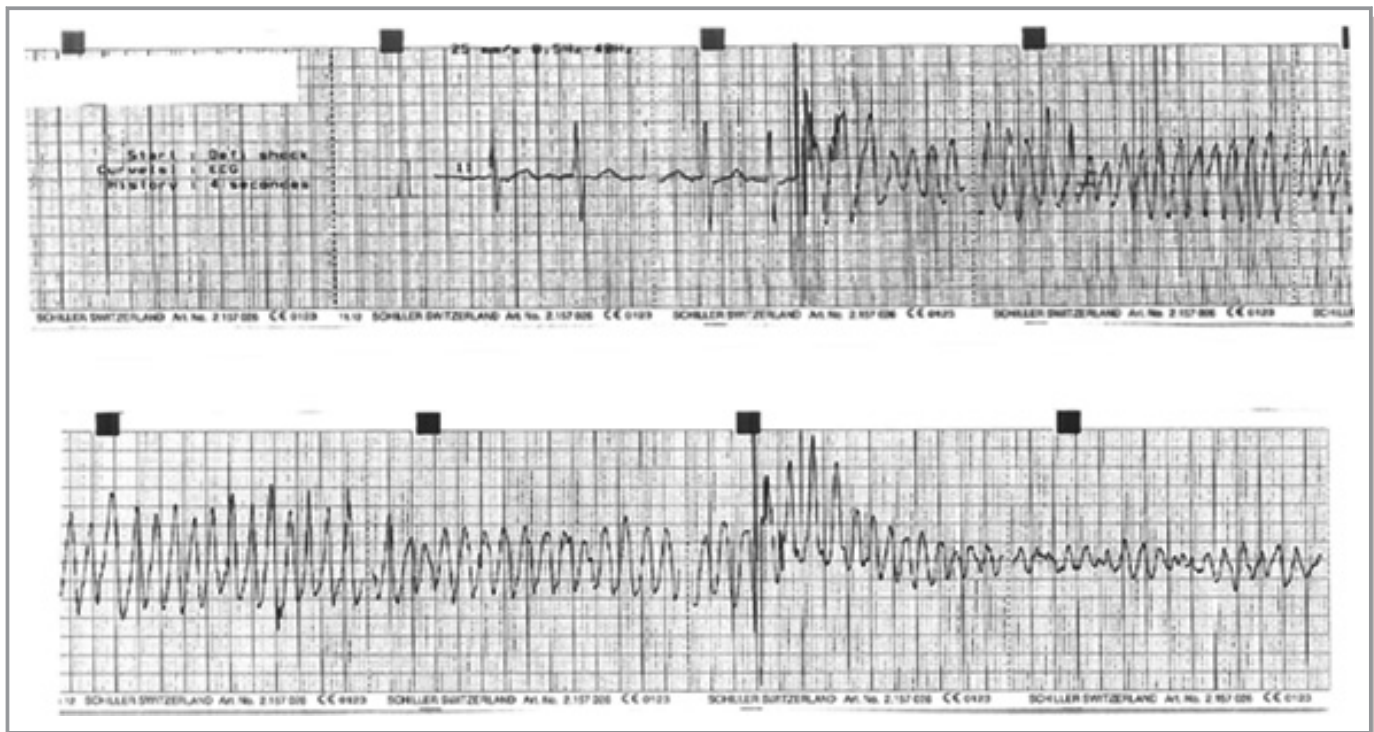
with our study, where more energy was required to cardiovert when using PB shocks compared with BTE shocks.

Importantly, the success rate of BTE shocks in our study (89% 1-minute postcardioversion and 86% at discharge) was in

accordance with other studies. Accordingly, a study comparing BTE shocks to rectilinear biphasic shocks report a success rate of 91%,<sup>15</sup> and similarly a success rate of 90% was found in a study comparing BTE shocks with monophasic shocks; both studies used a comparable shock energy protocol and end point (1-minute postcardioversion).<sup>6</sup> Furthermore, previous studies have compared other biphasic waveforms in cardioversion of AF and atrial flutter. A rectilinear waveform was compared to a BTE waveform, but no studies have reported a difference between these waveforms in cardioversion success.<sup>15,21–23</sup>

In this study, PB shocks were delivered up to the maximal energy output at 200 J allowed by the device. For BTE shocks, the maximum energy output used in this study was 250 J rather than the possible maximum 360 J. This was in order to not disadvantage the PB waveform and to allow a reasonable comparison between the 2 waveforms by maintaining parity in escalating energies between groups. Delivery of the BTE shocks at a maximal energy of 360 J may further increase the cardioversion success rate.

In this study, there was no difference in myocardial injury between waveforms and no changes in hs-cTnI were observed regardless of waveform and energy used. These findings are in accordance with previous studies, showing no increase in troponin I following cardioversion.<sup>21,24–28</sup> In our study, the risk of postshock arrhythmias was low, although we did experience 2 cases of ventricular arrhythmia. The use of a low-energy escalating protocol is currently recommended for



**Figure 4.** Rhythm strip printed out by the pulsed biphasic defibrillator (lead II).

cardioversion,<sup>2,13</sup> to minimize, eg, postcardioversion arrhythmias. However, a retrospective study reviewing 6398 cardioversion procedures found 5 cases of ventricular fibrillation, in which the energy selection was 50 to 100 J.<sup>29</sup> The risk of inducing ventricular arrhythmia after cardioversion may be increased when using low-energy shocks close to the defibrillation threshold, which correspond to the upper limit of vulnerability for inducing ventricular fibrillation.<sup>30</sup> Furthermore, a study found a higher first shock success and no increase in postshock arrhythmias when using a fixed high-energy biphasic shock protocol (200 J) compared with a low-energy escalating shock protocol (100–150–200 J).<sup>31</sup> Importantly, using higher energy selection for cardioversion may be considered to decrease the risk of induced ventricular arrhythmia, although the optimal shock energy protocol for biphasic cardioversion remains to be identified.

## Limitations

Ideally, the PB and BTE waveforms should be tested within the same device using the same defibrillation electrodes and exactly identical shock protocols. Importantly, the results of this study reflect the clinical use of the equipment, using the available energy settings in each device, allowing a reasonable comparison of the 2 waveforms. The study was terminated earlier than expected, with 16 patients below the calculated sample size. However, the actual difference in cardioversion success was much higher than expected according to the sample size estimation. This was because of a software failure where asynchronous shocks caused 2 cases of ventricular arrhythmia. It is well known that asynchronous shocks can cause this harm if applied in the vulnerable phase of the T-wave. However, it is unknown if shock delivery at other positions in the heart cycle might affect cardioversion efficacy. Lastly, despite randomization, treatment with amiodarone was unevenly distributed in the 2 groups, but the amiodarone-stratified subgroup analysis did not change the overall result of the study.

## Conclusions

This study demonstrated that when compared by energy levels, cardioversion using a BTE waveform was more effective compared to a PB waveform. There was no difference in myocardial injury between the 2 waveforms (ie, changes in troponin I levels).

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## Disclosures

Deakin served as the immediate past chair of ILCOR Advanced Life Support taskforce. The remaining authors have no disclosures to report.

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# **SUPPLEMENTAL MATERIAL**

**Table S1.** Characteristics of the 116 patients with atrial fibrillation and the 18 patients with atrial flutter.

Patient's characteristics	<i>AF patients</i>		<i>Atrial flutter patients</i>	
	PB waveform	BTE waveform	PB waveform	BTE waveform
<i>Demographics</i>				
No. of patients	60	56	9	9
Age, years (mean $\pm$ SD)	66 $\pm$ 9	66 $\pm$ 9	68 $\pm$ 11	70 $\pm$ 5
Male sex (%)	43 (72)	42 (75)	8 (89)	9 (100)
Atrial flutter	-	-	-	-
AF or -flutter duration in months, median (quartiles)	3 (2; 9)	5 (2; 23)	3 (2; 7)	8 (3; 44)
Prior cardioversions, median (quartiles)	0 (0; 0.25)	0 (0; 1)	0 (0; 0)	1 (0; 3)
Prior ablation, median (quartiles)	0 (0; 0)	0 (0; 0)	0 (0; 0)	0 (0; 1)
<i>Comorbidities, %</i>				
Hypertension	46 (77)	45 (80)	5 (56)	6 (67)
Congestive heart failure	18 (30)	10 (18)	2 (22)	2 (22)
Valvular heart disease	2 (3)	6 (11)	1 (11)	1 (11)
Thyroid disease	0 (0)	2 (4)	0 (0)	0 (0)
Prior stroke/transient ischemic attack	6 (10)	4 (7)	0 (0)	0 (0)
Prior myocardial infarction	1 (2)	5 (9)	0 (0)	0 (0)
Ischemic heart disease	12 (20)	12 (21)	1 (11)	0 (0)
Hyperlipidemia	25 (42)	26 (46)	4 (44)	2 (22)
Chronic obstructive pulmonary disease	2 (3)	4 (7)	0 (0)	1 (11)

*Cardiac medication, %*

Amiodarone	6 (10)	14 (25)	0 (0)	4 (44)
Digoxin	13 (22)	17 (30)	1 (11)	1 (11)
Flecainide	1 (2)	1 (2)	0 (0)	0 (0)
ACE/Angiotensin-II blocker	41 (68)	36 (64)	3 (33)	4 (44)
Beta blocker	49 (82)	46 (82)	8 (89)	7 (78)
Calcium antagonist	16 (26)	18 (32)	0 (0)	2 (22)

*Vital parameters and laboratory data*

Body mass index, kg/m <sup>2</sup>	29 ±6	31 ±5	28 ±5	28 ±7
Systolic blood pressure, mmHg	136 ±17	136 ±22	132 ±22	133 ±17
Diastolic blood pressure, mmHg	82 ±14	80 ±13	77 ±13	78 ±12
Heart rate before cardioversion, min <sup>-1</sup>	80 ±18	81 ±18	76 ±18	74 ±18
Estimated glomerular filtration rate	69 ±14	69 ±18	68 ±16	66 ±15
Hemoglobin (mmol/L)	9.3 ±0.8	9.4 ±0.9	8.9 ±0.7	8.9 ±1.0
Thyroid-stimulating hormone (IU x10 <sup>-3</sup> /L)	1.47 (1.00; 2.45)	1.67 (0.92;2.64)	1.70 (1.37; 2.59)	1.52 (1.19; 2.22)
Total propofol dose (mg)	116 ±44	108 ±35	89 ±26	96 ±14

*Patient's symptoms (EHRA Score), %*

I	27 (45)	22 (39)	4 (44)	4 (44)
II	28 (47)	24 (43)	3 (33)	5 (56)
III	5 (8)	10 (18)	2 (22)	0 (0)
IV	0 (0)	0 (0)	0 (0)	0 (0)

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Abbreviations: PB; Pulsed biphasic, BTE; Biphasic truncated exponential, AF; Atrial fibrillation, ACE;

Angiotensin converting enzyme, EHRA; European Heart Rhythm Association score of AF-related symptoms.



**Table S2.** Characteristics of the 24 patients receiving amiodarone treatment and the 110 patients not receiving amiodarone.

Patient's characteristics	<i>Receiving amiodarone</i>		<i>Not receiving amiodarone</i>	
	PB waveform	BTE waveform	PB waveform	BTE waveform
<i>Demographics</i>				
No. of patients	6	18	63	47
Age, years (mean $\pm$ SD)	59 $\pm$ 10	66 $\pm$ 9	67 $\pm$ 9	67 $\pm$ 8
Male sex (%)	5 (83)	16 (89)	46 (73)	35 (75)
Atrial flutter	9 (13)	9 (14)	9 (13)	9 (14)
AF or –flutter duration in months, median (quartiles)	11 (9; 18)	22 (5; 37)	3 (2; 7)	4 (2; 17)
Prior cardioversions, median (quartiles)	1 (1; 1.75)	2 (0.25; 3)	0 (0; 0)	0 (0; 0)
Prior pulmonary vein ablation, median (quartiles)	0 (0; 0)	0 (0; 1)	0 (0; 0)	0 (0; 0)
<i>Comorbidities, %</i>				
Hypertension	0 (0)	14 (78)	45 (71)	37 (79)
Congestive heart failure	3 (50)	4 (22)	7 (27)	8 (17)
Valvular heart disease	0 (0)	3 (17)	3 (5)	4 (9)
Thyroid disease	0 (0)	1 (6)	0 (0)	1 (2)
Prior stroke/transient ischemic attack	0 (0)	0 (0)	6 (10)	4 (8)
Prior myocardial infarction	0 (0)	1 (6)	1 (2)	4 (9)
Ischemic heart disease	2 (33)	3 (17)	11 (17)	9 (19)
Hyperlipidemia	2 (33)	7 (39)	27 (43)	21 (45)
Chronic obstructive pulmonary disease	0 (0)	1 (6)	2 (3)	4 (9)

*Cardiac medication, %*

Amiodarone	-	-	-	-
Digoxin	0 (0)	4 (22)	14 (22)	14 (30)
Flecainide	0 (0)	1 (6)	1 (2)	0 (0)
ACE/Angiotensin-II blockers	6 (100)	10 (55)	38 (60)	30 (64)
Beta blockers	4 (67)	11 (61)	53 (84)	42 (89)
Calcium channel blockers	3 (50)	4 (22)	13 (21)	16 (34)

*Vital parameters and laboratory data*

Body mass index, kg/m <sup>2</sup>	31 ±5	29 ±4	29 ±6	30 ±6
Systolic blood pressure, mmHg	145 ±15	130 ±22	135 ±18	137 ±21
Diastolic blood pressure, mmHg	91 ±11	80 ±14	81 ±14	79 ±13
Heart rate before cardioversion, min <sup>-1</sup>	86 ±27	85 ±25	80 ±20	79 ±14
Estimated glomerular filtration rate	71 ±17	64 ±19	69 ±14	70 ±16
Hemoglobin (mmol/L)	9.3 ±0.9	9.2 ±0.9	9.3 ±0.8	9.3 ±0.9
Thyroid-stimulating hormone (IU x10 <sup>-3</sup> /L)	3.00 (2.18; 3.69)	1.65 (1.08;2.70)	1.47 (0.99; 2.30)	1.67 (0.94; 2.44)
Total propofol dose (mg)	125 ±30	103 ±30	112 ±43	108 ±30

*Patient's symptoms (EHRA Score), %*

I	3 (50)	5 (28)	28 (44)	21 (45)
II	3 (50)	10 (56)	28 (44)	19 (41)
III	0 (0)	3 (17)	7 (11)	7 (15)
IV	0 (0)	0 (0)	0 (0)	0 (0)

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Abbreviations: PB; Pulsed biphasic, BTE; Biphasic truncated exponential, AF; Atrial fibrillation, ACE;

Angiotensin converting enzyme, EHRA; European Heart Rhythm Association score of AF-related symptoms.