Original article

Effects of shock polarity reversal on defibrillation threshold in an implantable cardioverter-defibrillator

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Abstract

Background: An increased defibrillation threshold (DFT) may limit the efficacy of an implantable cardioverter-defibrillator (ICD) in termination of life-threatening ventricular arrhythmias. A search for methods of decreasing DFT has been ongoing since the introduction of ICD into clinical practice.

Aim: To assess the effects of various shock polarities on DFT.

Methods: The study group consisted of 19 patients (8 females and 11 males, mean age 52±17 years) who received devices (Biotronik, Germany) with a single-coil defibrillation lead. In all patients the value of DFT was assessed using a normal shock polarity as well as using a reversed polarity shock, starting from the energy lower than that measured during normal DFT testing. The impedance of the defibrillation system using two different polarities was also measured. The effects of demographic and clinical parameters on defibrillation parameters were also examined.

Results: When using normal shock polarity, the mean DFT value was 12±5 J (range 3.1-20 J) and impedance was 64±12 Ω. When shock polarity was reversed, the mean DFT value was 9.2±5.0 J (range 2-20 J) and impedance was 67±11 Ω. In 11 (58%) patients the polarity change caused a marked (by 37%) decrease in the mean DFT value – from 11.5±5.1 J to 7.2±3.8 J. In 5 patients DFT reduction was ≥5 J. There was no relationship between demographic or clinical parameters and defibrillation efficacy using the two tested shock polarities.

Conclusions: The reversal of shock polarity reduces DFT in more than half of patients. In patients with a high DFT the use of reversed polarity of defibrillating impulse may reduce DFT, which widens the safety margin and makes implantation of additional leads unnecessary. Because clinical parameters have no value in predicting the effects of polarity changes on DFT, the efficacy of reversed polarity shock has to be assessed individually in each patient.

Key words: ICD, defibrillation threshold, shock polarity

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Introduction

Attempts to decrease the ventricular fibrillation (VF) defibrillation threshold (DFT) have continued since the introduction of implantable cardioverter-defibrillators (ICD) into clinical practice. Defibrillation threshold is defined as the lowest energy of a shock which effectively terminates VF. Direction of defibrillating current is one of the parameters which influence DFT value. In modern devices the polarity of defibrillating leads can be programmed. The most commonly used is so-called "normal" polarity in which the right ventricular lead serves as cathode. Such a shock polarity is a standard, nominal setting. The polarity of a biphasic shock is defined according to the direction of current during the first phase of a shock.

According to some investigators, the use of so-called "reversed" polarity of the defibrillating impulse, where the right ventricular lead serves as an anode, may decrease DFT. However, others did not confirm these findings [1, 2]. The present study was set to investigate the effects of shock polarity changes on DFT.

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Table I. Clinical characteristics of the studied patients

	Number of patients
Ventricular arrhythmias before ICD implantation	
Ventricular tachycardia	11
Ventricular fibrillation	7
Ventricular tachycardia and fibrillation	1
Underlying cardiac disease	
Ischaemic heart disease	12
Previous myocardial infarction	10
Post-infarction left ventricular aneurysm	2
Previous CABG	4
Previous aneurysmectomy	1
Idiopathic ventricular fibrillation	1
Hypertrophic cardiomyopathy	1
Long QT syndrome	4
Arrhythmogenic right ventricular cardiomyopathy	1
Antiarrhythmic therapy	
Amiodarone	4
Sotalol	5
Left ventricular ejection fraction [%]	46±23 (15-80)
NYHA class	
I	11 (61%)
II	6 (32%)
III	2 (11%)

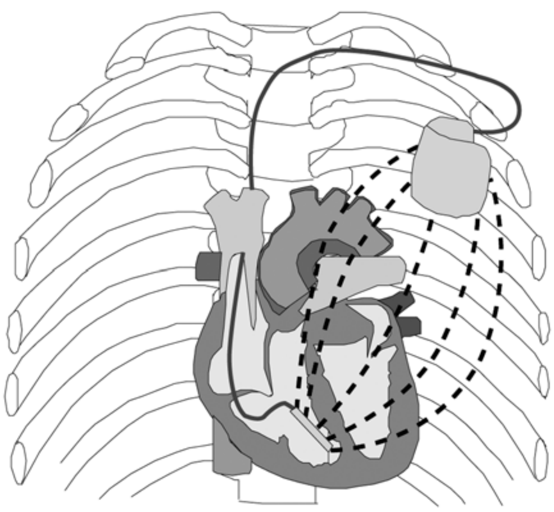

Figure 1. A single-coil device. Defibrillation current flows between electrode coil and ICD. The device is localised in the left subclavicular region

Methods

Patients

The study group consisted of 19 patients (8 females, 11 males, mean age 52±17 years, range 18-72 years) who were selected for ICD implantation. Clinical and demographic characteristics of the studied patients are presented in Table I.

Testing of DFT

All patients received the Biotronik (Germany) device with a single-coil defibrillating lead (Figure 1). The DFT testing was performed according to the DFT+ protocol [3, 4]. Parameters of both phases of the defibrillating impulse were as follows: voltage charging 100%, voltage of phase changes 40%, and interruption of an impulse at 20% of voltage charging. We used classical polarity shocks – the first phase of the impulse was negative, and the second positive. After the assessment of DFT was completed, the polarity of shock was changed and the first phase was positive, the second negative. Next, the reversed polarity shock, which was of lower energy than DFT determined for standard polarity, was tested for VF termination. When the reversed polarity shock was effective, DFT testing was continued using lower energy values, according to the protocol. When the first tested reversed polarity shock was ineffective, DFT testing was discontinued. The DFT protocol is presented in Figure 2. Also, the impedance values, using the two tested shock polarities, were measured.

The effects of age, gender, underlying disease, left ventricular end-diastolic diameter, left ventricular ejection fraction and NYHA class on the differences in DFT values were also examined.

Statistical analysis

The DFT values, demographic and clinical data are presented as mean±standard deviation. The effects of reversed shock polarity on DFT values were assessed using the analysis of variance (MANOVA) for repetitive measurements. The effects of clinical parameters on DFT values were examined using either the analysis of variance (MANOVA) for repetitive measurements or stepwise multivariate linear or logistic regression. A normal distribution of analysed parameters was examined using appropriate tests. A p value <0.05 was considered significant.

Results

The mean DFT value using a normal shock polarity was 12±5 J (range 3.1-20 J), and the system impedance was 64±12 Ω. When the polarity of shock was reversed,

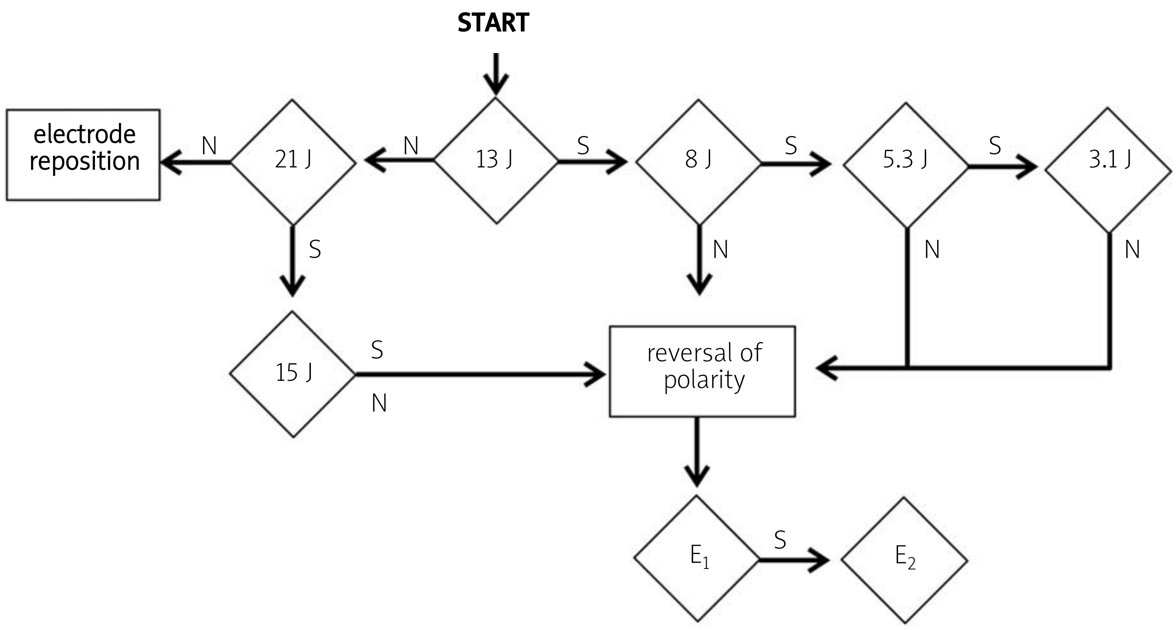

Figure 2. Defibrillation threshold testing protocol using different polarisations of defibrillating impulse. See text for details.

Abbreviations: S – successful, N – noneffective, E_1 – energy of first shock after polarity reversal, E_2 – energy of second shock after polarity reversal

the mean DFT value decreased to 9.2±5.0 J (2-20 J), ($p < 0.05$), whereas the impedance values remained similar at 67±11 Ω (NS).

The reversal of shock polarity reduced DFT in 11 (58%) patients. In the remaining 8 (42%) patients the reversed polarity shock, which was of lower energy than previously assessed standard DFT, was ineffective. According to the protocol, no reversed polarity DFT testing using higher energies was performed. This means that in these 8 patients the reversed polarity DFT was equal to or higher than that measured using normal polarity of defibrillating impulse.

In the group of patients in whom the reversal of shock polarity caused a decrease in DFT, the efficacy of VF defibrillation increased by 37% – from 11.5±5.1 J to 7.2±3.8 J. Figure 3 shows changes in DFT in those patients in whom DFT was decreased using a reversed polarity shock. In five patients the reduction of DFT was ≥5 J and devices were programmed with the reversed polarity of shock. The most pronounced reduction in DFT (by 13 J) was achieved in a patient in whom normal DFT was 18 J.

There was no relationship between the examined demographic or clinical parameters and DFT when using the reversed polarity shock.

Discussion

Since the introduction of ICD into clinical practice, a search has been ongoing for optimal polarity of defibrillating impulse, using various lead configurations or different defibrillating impulse waveforms. In the standard approach, the right ventricular lead serves as

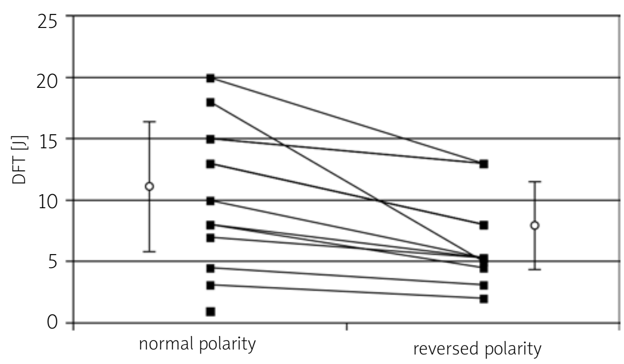

Figure 3. Changes in the defibrillation threshold (DFT) in patients in whom a reduction in DFT was achieved by a reversal in the polarisation of a defibrillating impulse

a cathode, and ICD can serve as an anode. Several studies have examined the effects of the direction of defibrillation current on DFT, but the results are inconsistent.

In the late eighties, the results of studies were published in which epicardial leads and monophasic defibrillation impulses were used. In the majority of patients, the right ventricular lead as cathode, and the left epicardial lead as anode, was the most effective lead configuration [5, 6]. These early studies already concluded that the optimal polarity of shock has to be individually assessed in each patient because clinical parameters failed to predict the most effective pattern of shock polarity [6].

In the mid nineties, after the introduction of transvenous ICD systems, the results of experimental [7, 8] and clinical studies [9, 10, 11] were published. These reports failed to show that the use of reversed shock polarity, using both mono- and biphasic waveforms, resulted in DFT decrease. In a study of 19 patients, Block et al. [9] did not find any significant difference between DFT measured using normal and reversed polarity of defibrillating impulse. Similar results were reported by Neuzner et al. [10] and Strickberger et al. [11], using the same lead system and biphasic waveform of defibrillating impulse.

The introduction of active-can devices was the next step in ICD development. An active can serves as an electrode during VF defibrillation. Several experimental and clinical studies were conducted using this type of ICD, but they failed to demonstrate the effects of polarity shock changes on DFT [12, 13]. Only Natale et al. [14] in a study which included 20 patients with ICD and bipolar lead were able to show that a biphasic defibrillating impulse of reversed polarity was more effective than a normal one in 60% of patients, whereas a standard shock polarity was superior only in 10% of patients. In another study, Shorofsky et al. [15] compared mono- and biphasic impulses in 26 patients with a bipolar lead ICD and found the reversed polarity shocks to be more effective when monophasic waveforms were used, whereas no such effect was observed for bipolar impulses. Of note, beneficial effects of polarity shock changes were predominantly seen in patients in whom DFT exceeded 15 J. Opposite results were reported by Schauerte et al. [16], who found that the reversal of shock polarity significantly reduced DFT also in biphasic devices. In addition, Olsovsky et al. [17] confirmed that the use of reversed shock polarity significantly improves efficacy of VF termination in patients with increased (≥15 J) DFT.

The mechanisms by which a change in shock polarity may affect DFT remain unknown. It is possible that shock efficacy depends on impulse duration. Schauerte et al. [18] compared the efficacy of biphasic defibrillating impulses with both polarities in relation to their duration. When shocks with an optimal duration (the lowest DFT) were compared, no differences between standard and reversed polarity shocks were found. The advantages of the reversed polarity shocks became clear and were more pronounced when impulses of duration more and more different from the most effective impulse duration were compared. An interesting explanation was presented by Stellbrink et al. [2], who showed that at the end of the second phase of an impulse with a reversed polarity, impedance of the defibrillation system is significantly lower than that of normal polarity, which may influence the efficacy of defibrillation.

In summary, in spite of numerous experimental and clinical studies, the superiority of one over another polarity of defibrillating impulse has not been documented. None of the studies identified any clinical factors which could predict higher efficacy of one of the polarity patterns.

In our study we found that a change in shock polarity resulted in a decrease in DFT by almost 40% in more than half of the studied patients, whereas it did not affect impedance of the defibrillating system. We also failed to identify any clinical factors associated with decreased DFT.

In the majority of implanting centres DFT is tested using a normal shock polarity. Our results indicate that a change in the defibrillating impulse polarity may reduce DFT in more than half of patients, particularly in those with initially high DFT. By changing impulse polarity, DFT can be decreased, safety margin widened and a more complex procedure with implantation of additional leads can be avoided. This approach is in line with recommendations recently published by Mainingi and Callans, based on their experience with 1100 patients who underwent ICD implantation [19, 20].

Unfortunately, clinical parameters are not helpful in predicting the effects of shock polarity changes on DFT. Therefore, reverse shock polarity requires individual testing in each case.

Limitations of the study

Using the DFT testing protocol, we were not able to compare the mean values of DFT using both defibrillating impulse polarities. Thus, the question of whether in the whole study group the mean DFT using reverse impulse polarisation was lower than the normal one remains open. The aim of the present study was to answer the question as to whether the use of reversed polarity shock is associated with decreased DFT, and therefore DFT assessment using reversed polarity was performed at lower energy level than the initial, normal DFT measurement. Such a protocol enabled limitation of the number of VF inductions and subsequent shocks during DFT testing.

Conclusions

1. The use of reversed polarity shocks is associated with decreased DFT in more than half of patients, which offers a larger safety margin and avoidance of more complex procedure with implantation of additional leads, which is particularly important in patients with initially high DFT.
2. Clinical parameters are not useful in predicting the effects of shock polarity reversal on DFT; therefore it requires individual assessment in each patient undergoing ICD implantation.

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Wpływ zmiany polaryzacji impulsu defibrylującego na próg defibrylacji migotania komór

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Streszczenie

Wstęp: Od czasu wprowadzenia wszczepialnych kardiowerterów-defibrylatorów serca (ICD) do praktyki klinicznej istotnym problemem pozostaje znalezienie sposobów obniżenia progu defibrylacji migotania komór (DFT).

Cel: Niniejsza praca jest poświęcona badaniu wpływu zmiany polaryzacji impulsu defibrylującego na DFT.

Metoda: Grupę badaną stanowiło 19 chorych (8 kobiet i 11 mężczyzn), w średnim wieku 52±17 lat, którym implantowano ICD firmy Biotronik z elektrodą wewnątrzsercową z pojedynczym obwodem defibrylującym. U wszystkich pacjentów oceniano wartość DFT przy zastosowaniu impulsu o polaryzacji klasycznej, skuteczność impulsu o odwróconej polaryzacji i energii niższej od wyznaczonego DFT oraz oporność układu defibrylującego przy zastosowaniu obu polaryzacji. Analizowano także wpływ czynników demograficznych i klinicznych na parametry defibrylacji.

Wyniki: Przy zastosowaniu klasycznego impulsu DFT wynosił średnio 12±5 J (3,1–20 J), a oporność defibrylacji 64±12 Ω. Natomiast po zmianie polaryzacji impulsu średnia wartość DFT wynosiła 9,2±5,0 J (2–20 J), a opór defibrylacji 67±11 Ω. U 11 (58%) pacjentów zmiana polaryzacji impulsu defibrylującego spowodowała obniżenie DFT o 37%, z 11,5±5,1 J do 7,2±3,8 J. U 5 chorych uzyskano redukcję DFT ≥5 J. Nie wykazano związku pomiędzy badanymi czynnikami klinicznymi a skutecznością defibrylacji dla impulsu o klasycznej i odwróconej polaryzacji.

Wnioski: Zmiana polaryzacji impulsu defibrylującego powoduje obniżenie DFT u ponad połowy pacjentów. U chorych z wysokim progiem defibrylacji migotania komór zastosowanie odwróconej polaryzacji może pozwolić na obniżenie DFT i uzyskanie większego marginesu bezpieczeństwa, a tym samym na uniknięcie rozleglejszego zabiegu z implantacją dodatkowych elektrod. Ponieważ na podstawie danych klinicznych nie można przewidzieć wpływu zmiany polaryzacji na wartość DFT, skuteczność impulsu defibrylującego o odwróconej polaryzacji wymaga zawsze indywidualnej oceny.

Słowa kluczowe: wszczepialny kardiowerter-defibrylator serca (ICD), próg defibrylacji migotania komór (DFT), polaryzacja impulsu defibrylującego

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