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Incidence of ineffective safety margin testing (<10 J) and efficacy of routine subcutaneous array insertion during implantable cardioverter defibrillator implantation ☆

Marc-Alexander Ohlow [a,*], *Marcus Roos* [b], *Bernward Lauer* [a],
J. Christoph Geller [c]

[a] *Department of Cardiology, Zentralklinik, Robert-Koch-Allee 9, 99437 Bad Berka, Germany*
[b] *Clinic for Electrophysiology, Heart Center, Salzburger Leite 1, 67616 Bad Neustadt, Germany*
[c] *Department of Invasive Electrophysiology, Zentralklinik, Robert-Koch-Allee 9, 99437 Bad Berka, Germany*

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ABSTRACT

The purpose of this study was to assess (1) the incidence of safety margin testing <10 J (SMT) and (2) the efficacy/safety of routinely adding a subcutaneous array (SQA) (Medtronic 6996SQ) for these patients.

Patients with SMT smaller than a 10-J safety margin from maximum output were considered to have very high readings and underwent SQA insertion. These patients were compared with the rest of the patients who had acceptable SMT ($\geq$10 J).

A total of 616 patients underwent ICD implantation during the analysis period. Of those, 16 (2.6%) had SMT <10 J. By univariate analysis, younger age, and non-ischemic cardiomyopathy, were all significant predictors of SMT <10 J (p < 0.05). In all 16 cases, other methods to improve SMT prior to array insertion were attempted but failed for all patients: reversing shock polarity (n = 15), removing the superior vena cava coil (n = 14), reprogramming shock waveform (n = 9), and repositioning right ventricular lead (n = 9). Addition of the SQA successfully increased SMT to within safety margin for all patients (32 $\pm$ 2 versus 21 $\pm$ 3 J; p < 0.001). Follow-up (mean 48.1 $\pm$ 21 months) was available for all patients with SQA, only 2 cases with inappropriate shocks due to atrial fibrillation had to be noted. None of the patients experienced complications due to SQA implantation.

SMT <10 J occur in about 2.6% of patients undergoing ICD implantation. SQA insertion corrects this problem without procedural/mid-term complications.

Introduction

The implantable cardioverter defibrillator (ICD) is widely accepted for primary and secondary prevention of severe life-threatening ventricular tachyarrhythmia. The Heart Rhythm Society updated appropriate use criteria for ICD therapy [1], however the incidence, risk factors, and management of safety margin testen <10 J (SMT) during implantable cardioverter defibrillator (ICD) testing are not well known.

The first small study in 1995 [2] and more previous studies [3,4] have demonstrated that additional insertion of a subcutaneous array (SQA) reduces mean defibrillation thresholds (DFT) of 20%–60%, depending on the electrode model used.

The purpose of this study was to assess the efficacy/safety of routinely adding a subcutaneous array (Medtronic 6996SQ) for patients with SMT <10 J during implantable cardioverter defibrillator (ICD) testing.

Methods

All consecutive patients undergoing initial ICD placement or generator replacement from January 2007 to December 2009 were analyzed in this retrospective, single-centre analysis.

Postimplantation ICD test protocol

Devices of all 4 important international companies (Biotronic, Medtronic, St. Jude Medical, Boston) were implanted. They were implanted in the catheter laboratory by 5 experienced invasive cardiologists. In all patients adequate ventricular sensing ($\geq$9 mV) and pacing threshold ($\leq$1 V) was confirmed. In the absence of absolute contraindications (eg thrombus formation in the left atrial appendage (LAA) or the left ventricle (LV)), an intra-operative ICD testing was routinely performed to prove a correct sensing, processing, shock delivery and termination of an induced VF. Our protocol for intra-operative ICD testing required at least one induction of VF with successful first shock terminating VF at a safety margin of at least 10 Joule (J) below the maximum output of the implanted device. If the first shock was not successful, a second shock at the maximum output of the device was delivered. In case this shock was still not successful an external defibrillation with 360 J biphasic shock was added. Patients with the need of a second shock at the maximum output or an external defibrillation to terminate induced VF were considered as ineffective SMT and were included in our study. Further management of these patients included intra-operative right ventricular lead reposition or an ICD-system modification such as addition or subtraction of the superior vena cava (SVC) shock coil and polarity reversal, respectively. In case the SMT was still ineffective, the implantation of a subcutaneous electrode array, considered to be the most effective method for reducing defibrillation threshold, was planned.

Subcutaneous electrode array Medtronic 6996SQ

The subcutaneous array electrode Medtronic 6996SQ consists of a single defibrillating coil of 25 cm length and has a diameter of 7.5 F, and an electrical cord ending with a 3.2 mm connector type DF-1. Total length of the electrode is 41 cm or 58 cm. That system is connected to the SVC socket of the implanted ICD. If a dual-coil intravascular lead is used, the subcutaneous electrode may be connected through the Y-connector to the SVC socket together with the proximal coil of the intravascular lead.

Implantation procedure of the 6996SQ electrode

The patient was lying flat, with the left upper limb abducted and an additional support under the left scapula. Local anesthesia was applied in the ICD pocket and along the designed course of the subcutaneous electrode. An incision was made in 10 cm distance of the ICD pocket. A stainless steel tunneling tool (6996ST provided by the manufacturer together with the electrode) with a dedicated sheath on was shaped appropriately and introduced via the small incision and further into the subcutaneous tissue along the chest wall, and towards the region below the inferior angle of the left scapula. Then the tunneling tool was removed and the electrode with an introducer inside was inserted into the sheath. Following that, the sheath was removed with a dedicated slittering tool, and the electrode itself was sutured in the pocket in a manner typical for intravascular leads. The electrode was tunneled from the incision into the ICD pocket and connected to the SVC socket of the ICD. Ideally the electrode along its course remained in the projection of the chest, and its end is located as close to the vertebral column as possible. In case of right sided ICD implantation the procedure itself does not differ from left sided implantations; however, the final tunneling to the ICD pocket has to be performed across the thorax and the end of the SQ array is located much more lateral because of the limited length of the array (Fig. 1).

Statistical analysis

The study group consisted of all patients with SMT <10 J, whereas the control group included all patients who did not develop this problem. Continuous variables were reported as mean value ± standard deviation or median and interquartile ranges (25th–75th percentiles) where appropriate. Categorical variables were presented as absolute (n) and relative (%) frequencies. Normal distribution of variables was assessed using the D'Agostino-Pearson omnibus normality test. Comparisons of continuous variables were made with the appropriate two-sample test; Student-t-test in cases where the variable was normally distributed. Otherwise, the Kruskal–Wallis test was used to identify risk factors for ILM. A probability value of $p \leq 0.05$ was considered statistically significant. Statistical analysis was performed using the GraphPad Prism version 6.02 for windows (GraphPad Software, La Jolla, California, USA).

Results

A total of 1221 patients underwent heart rhythm device implantation during the study period. Out of 632 analyzed ICD-recipients, 16 (2.5%) had no intra-operative defibrillation
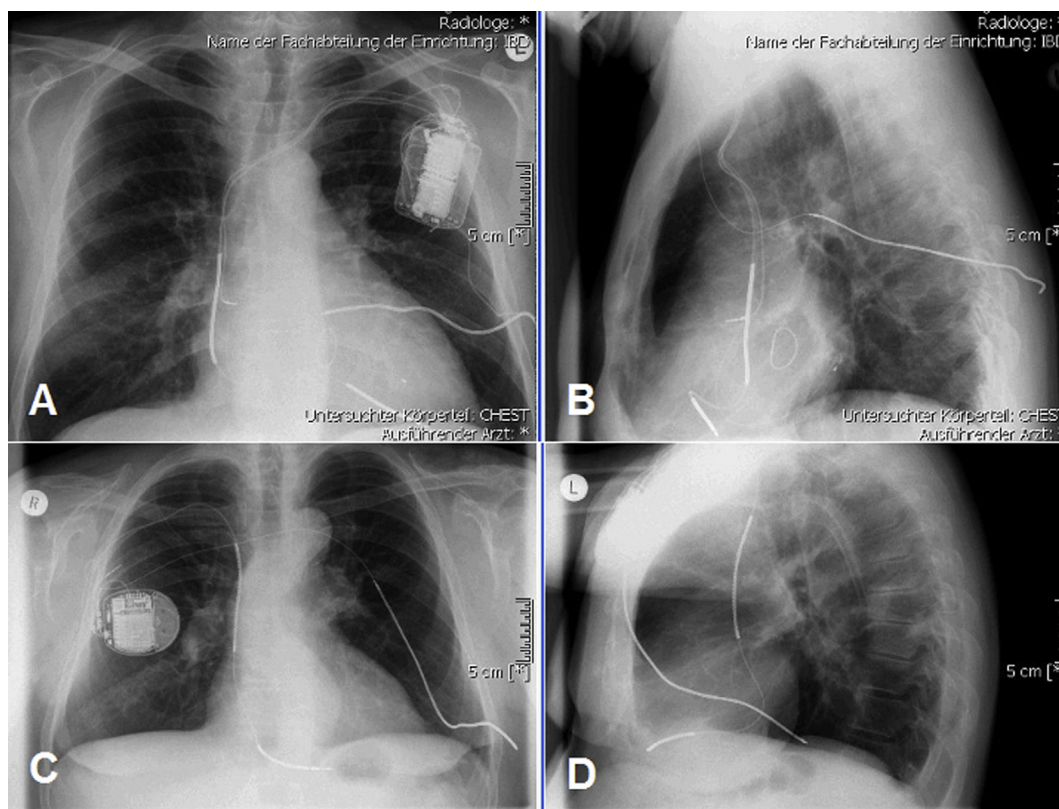
Fig. 1 – Chest x-ray image (posterior-anterior and lateral projection) of an ICD device plus subcutaneous array electrode (Panel A and B: left sided ICD implantation; Panel C and D: right sided ICD implantation).

testing [9 patients (1.4%) due to left atrial- or left ventricular thrombus and 7 (1.1%) due to decision of the operator (mainly atrial fibrillation with ineffective oral anticoagulation)]. Included in this retrospective analysis were 616 consecutive patients who received SMT following transvenous ICD implantation or ICD replacement. The population is described in Table 1; the device flow chart is shown in Fig. 2.

Effective defibrillation SMT was performed with a mean energy of 20.8 ± 2.3 J. In 16 patients (2.6%) induced VF could only be terminated with the maximum energy of the implanted device or with an external defibrillation (Table 1). There occurred no severe complications (death, major or minor strokes or cardiogenic shock) in any of the 616 SMT performed. The patients with ineffective SMT were younger (66.7 ± 10.6 years versus 54.6 ± 16.5 years; $p = 0.003$) and in univariate analysis they were less likely to have CAD as underlying diagnosis (31.3% versus 56.8%; $p = 0.05$). There was a trend for higher incidence of ineffective SMT in patients with myocarditis/inflammatory dilated cardiomyopathy compared to other form of non-ischemic cardiomyopathy (62.5% versus 37%), however this was not statistically significant ($p = 0.06$). Variables without impact on the efficiency of SMT included whether or not patients had a LVEF $\geq 20\%$, had a secondary preventive indication for ICD, were incomplete revascularized, had more than one main vessel significantly diseased and were taking a medication with amiodarone, respectively (Table 1).

In all 16 cases, other methods to improve SMT prior to SQ array insertion were attempted but failed for all patients:

reversing shock polarity [n = 15 (93.8%)], removing the superior vena cava coil [n = 14 (87.5%)], reprogramming shock waveform [n = 9 (56.3%)], and repositioning right ventricular lead [n = 9 (56.3%)]. Addition of the SQ array successfully increased SMT to within safety margin for all patients (30.9 ± 2 J without versus 21 ± 3 J with SQ array; $p < 0.001$). No complications related to subcutaneous array implantation occurred in our series.

Arrhythmic events during follow-up

The mean follow up was 48.1 ± 21 months and no death or resuscitation occurred during the follow up period. There were no problems (e.g. lead fracture, infection) noticed related to the subcutaneous array. Antiarrhythmic medication was equally balanced between both groups (Table 2). In general, there were more events in patients with effective SMT (23.2% versus 12.5%; $p = 0.55$). There were significantly more adequate therapies in patients with effective SMT (21.4% versus 0%; $p = 0.05$), whereas inadequate therapies were more frequently encountered in patients with initial ineffective SMT (12.5% versus 0.8%; $p = 0.01$).

Discussion

Our study represents a large data-set evaluating the impact of adding a subcutaneous array in patients with ineffective

Table 1 – Baseline characteristics.

			All	Effective SMT (≥10 J)	Ineffective SMT (<10 J)	p-value
Number, n (%)			616	600 (97.4)	16 (2.6)	
Sex						
	Male, n (%)		469	456 (76)	13 (81.3)	0.77
	Female, n (%)		147	144 (24)	3 (18.7)	
Age (years)	Mean (±SD)		66.4 (±11)	66.7 (±10.6)	54.6 (±16.5)	**0.0003**
	Median (IQR)		69 (60–74)	69 (62–74)	54 (41–69)	
LVEF (%)	Mean (±SD)		31 (±12.4)	31 (±12.5)	26.9 (±9.0)	0.86
	Median (IQR)		30 (22–35)	30 (23–35)	30 (20–35)	
LVEF ≤30%, n (%)			370 (59.9)	359 (59.8)	11 (68.8)	0.61 (>30% vs ≤30%)
LVEF ≤20%, n (%)			284 (46)	279 (46.5)	5 (31.2)	0.31 (>20% vs ≤20%)
BMI (kg/m2)	Mean (±SD)		28.4 (±4.7)	28 (±4.7)	29 (±4.0)	0.68
	Median (IQR)		28 (17–28)	28 (25–31)	29 (25.5–33)	
Indication	Primary prevention n (%)		466 (75.7)	453 (75.5)	13 (81.3)	0.77
	Secondary prevention n (%)		150 (24.3)	147 (24.5)	3 (18.7)	
	Type of arrhythmia for secondary prevention n (%)	sustained VT VF	108 (72) 42 (28)	107 (72.8) 40 (27.2)	1 (33.3) 2 (66.7)	p = 0.19 (VT vs VF)
SMT-energy (J)	Mean (±SD)		21 (±2.3)	20.8 (±2.3)	30.9 (±2.0)	**0.0001**
	Median (IQR)		20 (20–22)	20 (20–20)	30 (30–30)	
Diagnosis						
Non CAD, n (%)			270 (43.5)	259 (43.2)	11 (68.8)	
	DCM (myocarditis), n (%)		232 (37.7)	222 (37)	10 (62.5)	0.06 (myocarditis vs nonmyocarditis)
	Other CM (non myocarditis), n (%)		38 (6.2)	27 (6.2)	1 (6.3)	
CAD, n (%)			346 (56.2)	341 (56.8)	5 (31.3)	**0.05** (nonCAD vs CAD)
	Complete revascularized, n (%)		196 (56.3)	192 (56.3)	4 (80)	
	Not complete revascularized, n (%)		150 (43.7)	149 (43.7)	1 (20)	0.18 (complete vs in- complete revascularized)
Medication	Amiodarone medication, n (%)		123 (20)	118 (19.7)	5 (31.3)	0.34
	No amiodarone, n (%)		493 (80)	482 (80.3)	11 (68.7)	

BMI: body mass index; CAD: coronary artery disease; CM: cardiomyopathy; DCM: dilated cardiomyopathy; IQR: interquartile range; LVEF: left ventricular ejection fraction; n: number; n.s.: not significant; pp: primary prevention; SMT: safety margin test; SD: standard deviation; sp: secondary prevention; VF: ventricular fibrillation; VT: ventricular tachycardia.

safety margin testing following ICD-implantation. In particular, the relevant findings of this study are (1) SQ array implantation decreases DFT by mean 10 J to within safety margin for all patients; (2) the incidence of ineffective SMT was negatively affected by younger age and non-ischemic cardiomyopathy; and (3) there were no severe array related adverse events in any of the patients undergoing SQ array placement.

Efficacy of subcutaneous array implantation

Unsuccessful intra-operative SMT testing in terms of at least less than 10 J safety margin or necessity for external defibrillation was observed in 2.8% of our patients. This is significantly lower compared to the numbers in older publications [5,6] reporting consistently proportions of ~6% of the patients undergoing ICD implantation. Such patients in our study were younger and had underlying non-ischemic cardiomyopathy, although widely accepted "risk factors" predicting a SMT <10 J are not available. A study of Trusty et al. failed to reveal any correlation of preoperative characteristics with SMT <10 J [7]. However, several authors reported a wide spectrum of potential risk factors for SMT <10 J including high body-mass-index, large left ventricular diameter, or amiodarone medication [8,9]. It is important to remember that several drugs used for general anesthesia during the

implantation procedure can increase the minimally effective defibrillation threshold [10]. Off note, habitual cocaine use can cause high defibrillation thresholds [11], but this might not be relevant in daily clinical practice.

Consistent with other studies [2,3,6], adding a subcutaneous array in our study increased SMT by a mean of 10 J (from 31 J to 21 J). The higher the number of "fingers" of the subcutaneous array the lower the effects of the SMT was the main conclusion of a randomized study investigating the efficacy of different array types [3]. The subcutaneous array electrode Medtronic 6996SQ used in our series providing a single defibrillation coil might be potentially the most effective tool to solve the problem of high DFT.

To test or not to test

In 3 decades of clinical use of the implantable cardioverter defibrillator, defibrillation threshold testing has remained an integral part of the initial implantation procedure [12]. The prevailing rationale for the routine evaluation of SMT has been to ensure appropriate sensing of ventricular fibrillation, system integrity, and effective defibrillation [12]. Early in the development of the transvenous ICD, defibrillation threshold testing was performed by connecting the transvenous lead to an external cardioverter defibrillator using high-voltage
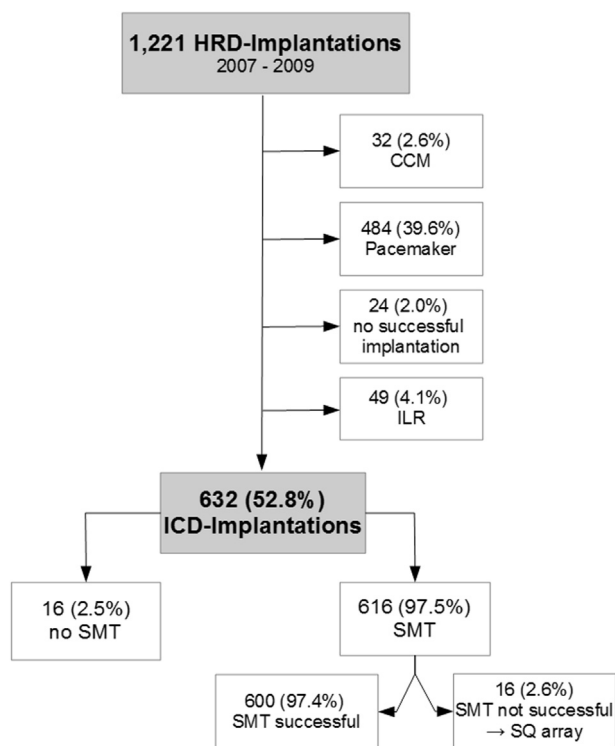
Fig. 2 – Device flow chart (CCM: cardiac contractility modulation; HRD: heart rhythm devices; ICD: implantable cardioverter defibrillator; ILR: implantable loop recorder; SMT: safety margin testing; SQ: subcutaneous).

been associated with worse clinical outcomes [14]. Contemporary ICD systems using active cans, biphasic waveforms, and intravascular high-voltage leads have considerably lowered the incidence of SMT <10 J [15,16]. The reliability of current ICD systems has led implanting physicians to abandon the practice of routine testing of defibrillation efficacy before hospital discharge and annually [12,13]. Based on a growing body of evidence the clinical utility of the determination of defibrillation efficacy during de-novo implants has been questioned in observational studies [15,17] as well as in randomized trials [18,19]. Currently, there is a widely accepted consensus that SMT at the time of ICD-implantation, although it seems to be safe, has no impact on post implant outcomes and first shock efficacy. However, this does not apply to patients undergoing implantation of a subcutaneous ICD, to patients with right sided ICD-implantation, and to patients who might have a potential problem with their ICD-system post implant that might warrant safety margin testing [13]. For the latter groups of patients and for patients with ineffective adequate ICD-shock delivery during daily life subcutaneous array implantation represents a very effective but low risk method for DFT lowering.

Limitations

Several limitations of the study merit further discussion. First, this study is subject to limitations inherent in non-randomized retrospective studies. Second, although the number analyzed patients undergoing ICD implantation is high, the total number of patients finally receiving a SQ array was low. Therefore the conclusions of our study are only preliminary.

Conclusions

Our study demonstrates that SQ array implantation in individuals with SMT <10 J decreases DFT by mean 10 J to within safety margin for all patients, the incidence of SMT <10 J was affected by younger age and non-ischemic cardiomyopathy, and there were no severe SQ array related adverse events

cables. The device itself was only implanted when external testing was successful [13]. Over time, device-based testing could be performed. Technically, the DFT is a probabilistic phenomenon requiring multiple shocks to determine with precision. Clinically, the SMT is commonly approximated with 1 or more shocks to terminate induced ventricular fibrillation and ensure a safety margin between the DFT and the maximum output of the ICD. Inadequate safety margins of 10 J between the DFT and maximum ICD energy delivery have

Table 2 – Follow up data.					
		All	Effective SMT (≥10 J)	Ineffective SMT (<10 J)	p-value
Follow up, n (%)		550 (89.3)	534 (89)	16 (100)	0.40
FU duration (months)	Mean (±SD)	48.1 (±21)	52.5 (±21)	43.8 (±21)	0.56
Antiarrhythmic drugs, n (%)					
	Amiodarone	128 (23.3)	122 (22.9)	6 (37.5)	0.23
	Sotalex	2 (0.4)	2 (0.4)	0 (0)	1.00
	β-Blocker	500 (90.9)	485 (90.8)	15 (93.8)	1.00
Events during FU, n (%)		126 (22.9)	124 (23.2)	2 (12.5)	0.55
	Inadequate therapy	6 (1.1)	4 (0.8)	2 (12.5)	**0.01**
	Adequate therapy	114 (20.7)	114 (21.4)	0 (0)	**0.05**
	ATP	58 (10.6%)	58 (10.9)	0 (0)	0.39
	Shock delivery	36 (6.6%)	36 (6.7)	0 (0)	0.62
	ATP and shock delivery	20 (3.6%)	20 (3.8)	0 (0)	1.00
	VT ablation	6 (1.1%)	6 (1.1)	0 (0)	1.00
FU: follow up; ATP: anti tachycardia pacing. Additional abbreviations in Table 1.					

during follow-up in any of the patients. Although routine intra-operative safety margin testing has decreased significantly over the past years (and will continue doing so in the future) SQ array placement is a very effective but low risk method for selected patients for DFT lowering.

Conflict of interest

There was no financial support/funding and no conflicts of interest of any of the authors have to be declared.

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