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Single-brand dual-chamber discriminators to prevent inappropriate shocks in patients implanted with prophylactic implantable cardioverter defibrillators: a propensity-weighted comparison of single- and dual-chamber devices

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Abstract

Purpose Comparisons of the efficacy of dual- vs. single-chamber implantable cardioverter defibrillators (ICDs) in preventing inappropriate shocks have had contradictory results. We investigated whether dual-chamber devices have a lower risk of inappropriate shocks and the specific role of supraventricular tachycardia (SVT) discriminators.

Methods All heart failure (HF) patients without an indication for pacing and implanted with a prophylactic ICD were recruited from the nationwide multicenter UMBRELLA registry. Arrhythmic events were collected by remote monitoring and reviewed by a committee of experts.

Results Among 782 patients, single-chamber ICDs were implanted in 537 (68.7%) and dual-chamber devices in 245 (31.3%). During a mean follow-up of 52.2 ± 24.5 months, 109 inappropriate shocks were delivered in 49 patients (6.2%). In the propensity-score-matched analysis, dual-chamber ICDs were related to lower rates of inappropriate shocks as compared to single-chamber devices (0.9% vs. 11.8%, $p = < 0.001$, log-rank test). In multivariable Cox proportional analysis, independent predictors of inappropriate shock were history of atrial fibrillation (hazard ratio (HR) = 2.78, CI 1.37–5.64, $p = 0.004$), chronic kidney disease (HR = 6.15, CI 2.82–13.53, $p < 0.001$), and non-ischemic cardiomyopathy (HR = 2.84, CI 1.54–5.23, $p = 0.001$). Among ICD settings, PR logic was the only discriminator independently related to a reduced risk of inappropriate shocks (HR = 0.18, CI 0.06–0.48, $p = 0.001$), along with an SVT limit enabled over 200 bpm (HR = 0.24, CI 0.11–0.51, $p < 0.001$).

Conclusions In this nationwide cohort of primary prevention ICD-only patients, dual-chamber devices were related to lower risk of inappropriate shocks compared to single-chamber ICDs. Besides, PR logic and SVT limit > 200 bpm emerged as protective factors.

Keywords Inappropriate shock · Dual-chamber · Implantable cardioverter defibrillator · PR logic · Atrial fibrillation

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1 Introduction

Implantable cardioverter defibrillators (ICDs) are the cornerstone of preventing sudden death in heart failure (HF) patients with impaired left ventricle ejection fraction (LVEF). Mortality is reduced with proper detection and subsequent treatment of life-threatening ventricular arrhythmias [1]. Although ICD shocks are lifesaving, they are also associated with an increased risk of death and worsening of HF [2, 3]. These drawbacks become more important when shocks are delivered for episodes of non-lethal ventricular arrhythmia. Inappropriate shocks are one of the most adverse events in ICD recipients, potentially leading to pain, posttraumatic

stress disorders, impaired quality of life, and even proarrhythmia [4]. The proportion of patients receiving an inappropriate shock has decreased, with annual rates currently ranging between 1 and 5% [5]. As the most common cause of inappropriate shocks is rapidly conducted supraventricular tachycardia (SVT) [6], the use of atrial and ventricular information provided by dual-chamber ICDs should enhance the discrimination of lethal ventricular arrhythmia. Nevertheless, both randomized studies [7–13] and observational reports [14–18] have given inconsistent results regarding the benefit of dual-chamber devices. Potential explanations for these inconclusive results are different programming strategies, small samples, and the inclusion of secondary prevention ICD patients, those with pacing indication, and cardiac resynchronization carriers.

Current guidelines on ICD programming recommend a longer detection time and higher rate cutoffs to prevent inappropriate shocks [19]. However, specific recommendations regarding SVT discrimination algorithms are weaker because the differential role that these algorithms play in clinical practice has been difficult to isolate.

We compared the risk of inappropriate shocks among single- and dual-chamber devices in a nationwide cohort of real-life HF patients receiving a prophylactic ICD. We focused on whether dual-chamber discriminators are associated with a lower risk of inappropriate shocks.

2 Methods

2.1 Patient selection

The present substudy was developed within the framework of the Scientific Cooperation Platform (SCOOP) supported within the UMBRELLA observational study (ClinicalTrials.gov/NCT01561144), which is a voluntary registry promoted by Medtronic Iberica that includes patients with Medtronic ICDs and follows them by remote monitoring (CareLink®) for both primary and secondary prevention. The institutional review board of the participating centers approved patient inclusion and all patients provided informed consent. Tachyarrhythmia detection and ICD settings were programmed at the discretion of local physicians.

Our target was to obtain a homogeneous population as close as possible to MADIT II and SCD-HeFT patients. Therefore, all HF patients with reduced LVEF undergoing their first prophylactic ICD-only implant and enrolled in the UMBRELLA registry were recruited. Patients included in the database after replacement procedures were excluded to avoid bias created by the collection of retrospective information. Patients with an antibradycardia pacing indication were also excluded because ventricular pacing has been related to unfavorable outcomes [20]. In addition, cardiac resynchronization therapy (CRT) carriers were not included in order to avoid the bias generated by improving LVEF.

2.2 Endpoint definitions and follow-up

The primary endpoint was inappropriate shock, which was defined as a shock delivered during rhythms other than ventricular tachycardia (VT) or ventricular fibrillation (VF). If more than one shock was needed to terminate the same arrhythmic episode, only one event was considered for further analysis. All inappropriate events were collected, and follow-up started from first ICD implantation until death or the end of the study period (September 2017).

Other clinical secondary endpoints, such as all-cause death and HF hospitalizations during follow-up, were also recorded and confirmed using the primary healthcare records of each participating center. First appropriate ICD shock was also analyzed as a secondary endpoint. Data on the specific cause of inappropriate and appropriate shocks were confirmed as described below.

2.3 Electrogram analysis and arrhythmic events

A committee composed of six experts analyzed all electrograms stored in the CareLink® network. Two committee members reviewed each event in a double-blind manner, classifying the type of arrhythmia and the effectiveness of the delivered therapy. Type of arrhythmia was classified as ventricular, supraventricular, T-wave oversensing, false detection, or noise. Supraventricular arrhythmia was further classified into atrial fibrillation (AF), sinus tachycardia (ST), or other regular SVT. The appropriateness of every therapy delivered was then adjudicated for the events. If disagreement occurred between the first two reviewers, the event was referred to a third reviewer. If no agreement was reached between two of the three reviewers, the event was reassigned to a new pair of reviewers and, if necessary, a sixth reviewer. If consensus was not reached at this point, the event was classified in a joint meeting of all committee members.

2.4 Statistical analysis

Continuous variables were expressed as mean ± standard deviation (SD) and categorical data as numbers or percentages. Continuous variables were compared using the Student t test when normally distributed and the Mann-Whitney U test when not normally distributed. Categorical variables were compared using χ^2 or the Fisher exact test when the conditions required for the former test were not met.

A propensity score (PS)-matched analysis was performed to study the risk of inappropriate shocks between patients receiving single- vs. dual-chamber ICDs. The PS was calculated using an ordered logistic regression model, taking type of device as the dependent variable and adopting a parsimonious approach. In a first step, all baseline characteristics were

included in the univariable analysis. All variables with $p < 0.2$ were entered into a multivariable ordered logistic regression model, which served to estimate the PS for each patient. Patient matching was performed in a 1:1 ratio using the nearest neighbor method (caliper = 0.2 × SD [logitPs]). The cumulative probability of inappropriate shocks among matched subgroups was described using Kaplan–Meier curves, and significance was assessed by the log-rank test.

A univariable Cox proportional hazard regression analysis was performed to identify variables predictive of inappropriate shocks in the overall population. A stepwise multivariable Cox regression analysis was performed in order to avoid potential confounding factors. Variables with the potential to act as confounding factors were selected according to the following criteria: the clinical and biological plausibility and, the statistical criterion of Mickey, excluding all variables that returned a p value > 0.2 after univariable analysis. Data were expressed as hazard ratios (HRs) and 95% confidence intervals (CIs). Statistical analysis was performed from the binomial distribution using the Statistical Package for Social Sciences (version 20.0, SPSS, Inc., Chicago, IL, USA). $p < 0.05$ was considered significant for all tests.

3 Results

3.1 Patient characteristics

The study population consisted of 782 patients who met the inclusion criteria and none of the exclusion criteria from the UMBRELLA database. ICD implantation was performed in 23 different Spanish hospitals between March 2006 and August 2015. A single-chamber ICD was implanted in more than two thirds of the population ($n = 537$, 68.7%) whereas dual-chamber devices were implanted in the remaining 245 cases (31.3%). The baseline characteristics of the overall population are summarized in Table 1 according to type of device. Patients receiving dual-chamber ICDs had wider QRS complexes, were more likely to present with a left bundle branch block (LBBB) pattern, had a greater history of HF admission, and angiotensin-converting enzyme inhibitors (ACEIs) or angiotensin II receptor blockers (ARBs) were prescribed more often. Otherwise, single-chamber devices were more frequently implanted in patients with a history of AF.

The ICD settings among study groups are shown in Table 2. Programming followed current recommendations for primary prevention patients as a rate cutoffs > 188 bpm was activated in 95% of patients. Only 38.1% of patients were programmed with 30 of 40 interval detections within the VF detection zone. As recommended, an antitachycardia pacing (ATP)-capable zone (FVT detection zone) was enabled through the VF zone in 28.7% of patients. This setting was programmed more frequently in single-chamber devices. SVT discriminators were enabled over the limit of 200 bpm in 74.5% of the patients and in 82.5% of dual-chamber recipients ($p < 0.001$). A morphology discriminator (wavelet) was activated in a majority of the population (81.4%) and significantly more often in dual-chamber patients, whereas a regularity discriminator (stability) was more frequently programmed in single-chamber ICDs ($p = 0.001$). An onset discriminator was scarcely used (7.4%), whereas T-wave oversensing was activated in almost all of the patients and PR logic was used in up to 95% of dual-chamber recipients.

3.2 Inappropriate shocks at follow-up

During a mean follow-up of 52.2 months (± 24.5), 109 inappropriate shocks were delivered in 49 patients (6.2% of the overall population). The mean number of inappropriate events per patient was 2.3 (± 2.8) and was significantly higher in recipients of single-chamber devices (2.4 ± 3.1 episodes) compared to dual-chamber devices (1.1 ± 0.4 episodes; $p = 0.047$). The main causes of arrhythmic events leading to inappropriate shocks were episodes of AF with rapid ventricular conduction ($n = 62$, 56.9%). The remaining causes were noise ($n = 19$ episodes, 17.4%), other regular SVT ($n = 16$ episodes, 14.7%), T-wave oversensing ($n = 9$ cases, 8.2%), and sinus tachycardia ($n = 3$, 2.8%).

In the entire cohort, inappropriate shocks occurred in 7.8% ($n = 42$) of patients receiving single-chamber ICDs and in 2.9% ($n = 7$) of dual-chamber ICD patients (HR = 3.94; 95% CI 1.77–8.78; $p = 0.001$). Moreover, inappropriate shocks were not related to a higher risk of HF admission (38.2% vs. 37.3%, respectively for patients who received an inappropriate shock and those who did not; HR = 1.05; 95% CI 0.52–2.11; $p = 0.885$), or all-cause death (crude mortality rates of 20.4% vs. 18.3%; HR = 1.21; 95% CI 0.64–2.33; $p = 0.545$) but they were linked to an increased risk of appropriate ICD therapies (7%/year vs. 3.81%/year; HR = 1.72; 95% CI 1.01–2.95; $p = 0.047$) after unadjusted analysis.

3.3 Inappropriate shocks among single- and dual-chamber ICD-matched patients

PS matched analysis performed in a 1:1 ratio including the variables asymmetrically distributed in the univariable analysis resulted in 220 patients whose baseline characteristics and ICD settings are shown in Tables 1 and 2, respectively. After a median follow-up of 52.3 months (IQR, 35.2–69.2), 13 patients with a single-chamber device received an inappropriate shock, whereas only one patient with a dual-chamber device was shocked. The weighted sample was well balanced regarding device settings (Table 2); however, a significantly higher risk of inappropriate shocks was found among patients implanted with single-chamber ICDs than those implanted with dual-chamber devices (11.8% vs. 0.9%; $p = < 0.001$, log-rank

Table 1 Baseline clinical characteristics in overall and propensity-matched population according to type of device

	Overall population				Propensity-matched population			
	Total population (*N* = 782)	Single-chamber (*N* = 537)	Dual-chamber (*N* = 245)	*p* value	Total population (*N* = 220)	Single-chamber (*N* = 110)	Dual-chamber (*N* = 110)	*p* value
Age (years)	61.1 ± 11.5	60.7 ± 11.6	61.8 ± 11.3	0.301	59.4 ± 11	58 ± 11.1	60.8 ± 10.8	0.087
Female gender	11.9%	11.4%	13.1%	0.495	13.2%	10%	16.4%	0.163
Diabetes	35.6%	37.5%	31.4%	0.100	31.8%	28.2%	35.5%	0.247
Hypertension	57.5%	59.4%	53.5%	0.129	52.3%	51.8%	52.7%	0.893
Smoker	48.7%	49.3%	47.6%	0.677	48.3%	49.5%	47.2%	0.739
Dyslipemia	56.6%	58.3%	52.8%	0.153	55%	55.5%	54.5%	0.892
Stroke	6.5%	6.4%	6.6%	0.943	6.8%	6%	7.5%	0.659
COPD	13.1%	13.5%	12.4%	0.727	10.9%	11.8%	10%	0.665
CKD*	15.4%	14.7%	17%	0.418	18.7%	16.5%	20.9%	0.404
NICM	28.9%	28.3%	30.2%	0.587	31.8%	34.5%	29.1%	0.385
Atrial fibrillation	26.7%	32.1%	14.9%	< 0.001	16.9%	18.3%	15.5%	0.568
NYHA class				0.969				0.880
• I–II	82.1%	82.1	82.1%		78.5%	79.6%	77.3%	
• III–IV	17.9%	17.9%	17.9%		21.5%	20.4%	22.7%	
LBBB like pattern	13.8%	11.9%	18%	0.023	12.3%	13.6%	10.9%	0.538
Previous HF admission	76.6%	74.5%	81.2%	0.040	81.8%	81.8%	81.8%	1.000
Mean QRS duration (ms)	108.9 ± 24.7	106.1 ± 23.4	114.8 ± 26.4	< 0.001	107.6 ± 22.4	108.6 ± 25	106.5 ± 19.5	0.960
LVEF, mean (%)	26.9 ± 5.4	26.9 ± 5.3	26.9 ± 5.4	0.914	27.2 ± 4.9	26.7 ± 4.9	27.7 ± 4.8	0.104
Beta blockers	90.9%	89.5%	93.1%	0.172	91.8%	91.8%	91.8%	1.000
ACEI or ARB	84%	79%	91.6%	< 0.001	88.6%	88.2%	89.1%	0.832
Aldosterone antagonists	59.4%	60.3%	57.9%	0.589	57.4%	60%	52.7%	0.277
Amiodarone	7.3%	7.5%	6.9%	0.796	7.7%	8.2%	7.3%	0.801

ACEI, angiotensin-converting enzyme inhibitors; *ARB*, angiotensin II receptor blockers; *CKD*, chronic kidney disease; *COPD*, chronic obstructive pulmonary disease; *GFR*, glomerular filtration rate; *HF*, heart failure; *LBBB*, left bundle branch block; *LVEF*, left ventricle ejection fraction; *ms*, milliseconds; *NICM*, non-ischemic cardiomyopathy

*GFR < 60 ml/min/1.73 m^2

test). Kaplan–Meier curves illustrating time to inappropriate shock are displayed in Fig. 1.

3.4 Predictors of inappropriate shocks

Univariable and multivariable Cox proportional regression analyses is shown in Table 3. The final multivariable model included the following clinical variables: non-ischemic cardiomyopathy (NICM), chronic kidney disease (CKD), previous AF, and LVEF as continuous parameter. The model included the following ICD settings: 30 of 40 intervals within the VF detection zone, FVT detection zone enabled, SVT limit > 200 bpm, stability, wavelet, and PR logic. Non-ischemic cardiomyopathy, previous AF, and CKD were identified as independent predictors of inappropriate shocks after multivariable adjustment. Among ICD settings, PR logic emerged as a strong protective parameter, and it was the only SVT discriminator related to a lower risk of inappropriate shocks. Furthermore, programming the SVT limit > 200 bpm was associated with fewer inappropriate events requiring shocks.

4 Discussion

This nationwide study of HF patients with no indication for pacing and implanted with a prophylactic ICD illustrates contemporary clinical practice. Several findings are worth noting. First, dual-chamber ICDs are related to a lower risk of inappropriate shocks, even after weighing both study groups. Second, PR logic emerged as the only SVT discriminator with a protective association regarding inappropriate shocks. Third, CKD, previous AF, and NICM are predictors of inappropriate

Table 2 ICD settings among single- and dual-chamber devices in overall and propensity-matched population

	Overall population			Propensity-matched population		
	Single-chamber ($N = 537$)	Dual-chamber ($N = 245$)	p value	Single-chamber ($N = 110$)	Dual-chamber ($N = 110$)	p value
VF detection zone cutoff > 188 bpm	94.6%	96.2%	0.255	96.4%	97.3%	0.701
30 of 40 intervals in VF zone	40.5%	35.6%	0.196	43.6%	33.6%	0.128
FVT programmed[a]	31.6%	22.6%	0.011	25.5%	22.7%	0.636
FVT detection zone cutoff (ms)	266.7 ± 24.8	266.7 ± 31.5	0.377	274.5 ± 26.2	262.7 ± 24	0.080
Dual zone programmed[b]	52%	48.1%	0.325	52.7%	42.7%	0.138
SVT limit > 200 bpm	70.8%	82.5%	0.001	80%	78.2%	0.740
Onset	8.1%	5.9%	0.274	4.5%	6.4%	0.553
Stability	24.7%	14.2%	0.001	17.3%	18.2%	0.860
Wavelet	76.4%	97.4%	< 0.001	95.5%	97.2%	0.556
PR logic	NA	95%	NA	NA	95.4%	NA
T-wave oversensing	99.7%	100%	0.478	100%	100%	1.000
High-rate time out	9.5%	5.9%	0.136	6.8%	5.7%	0.777

Bpm, beats per minute; *ICD*, implantable cardioverter defibrillator; *FVT*, fast ventricular tachycardia; *ms*, milliseconds; *NA*, non-appropriate; *SVT*, supraventricular tachycardia; *VF*, ventricular fibrillation

[a] Through VF detection zone

[b] Ventricular tachycardia detection zone programmed despite VF or FVT detection zone

shocks. Finally, AF is still the most common cause of inappropriate shocks.

Theoretically, dual-chamber discrimination of ventricular tachyarrhythmia and supraventricular tachyarrhythmia should be better than single-chamber discrimination. Although some trials have proven the accuracy of dual-chamber devices in simulated SVT detection [8, 21, 22], the superiority of dual-chamber ICDs in preventing inappropriate shocks in clinical practice is controversial. There may be several reasons for these conflicting results. First, some randomized studies investigating inappropriate shocks in dual- vs. single-chamber ICDs had a small sample size [7, 8, 12], which limits the power to detect statistical differences. However, a larger trial comparing devices from two manufacturers also failed to demonstrate superiority of dual-chamber ICDs [9]. Another explanation is the inclusion of a great proportion of secondary prevention patients in some of these trials [7, 10, 11]. The arrhythmic profile of primary prevention ICD recipients is different from the profile of secondary prevention ICD recipients. VT occurs at a faster rate in primary prevention patients, which decreases the rate of overlap between VT/VF and SVT. Another potential explanation is the lack of an optimal programming with higher detection rates and long intervals [9]. The only trial to show a significant reduction in inappropriate shocks in a dual- vs. single-chamber setting was the OPTION trial [13]. Programming in this trial was adjusted to current recommendations, but it also included a significant proportion of secondary prevention patients. These same problems arose again in several large clinical registries including primary prevention ICD recipients. In the Danish ICD registry, 1609 patients were studied, and those implanted with dual-chamber ICDs were at a higher risk of inappropriate shocks compared to single-chamber ICDs. The authors attributed this finding to a worse prognosis in dual-chamber ICD recipients and a higher number of pacing indications and CRT carriers in this subgroup [18]. In the retrospective Israeli ICD registry, dual-chamber devices were related to a lower risk of inappropriate therapy in a subgroup of ischemic patients but not in the entire cohort [16]. In a recent observational study of 1042 primary prevention ICD-only patients in US clinical practice, dual-

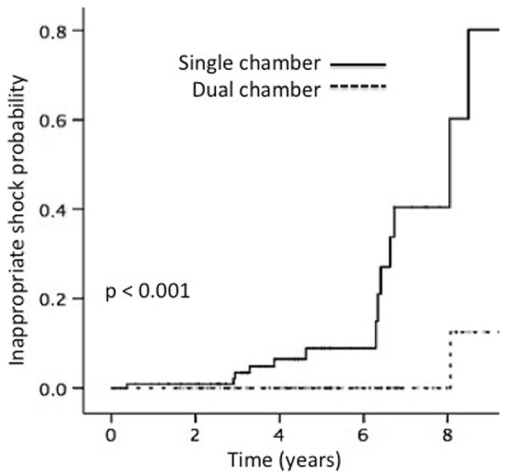

Fig. 1 Cumulative incidence of inappropriate shocks among single- and dual-chamber devices in the propensity score–matched population. *p*-values correspond to log-rank test

Table 3 Predictors of inappropriate shock on univariable and final multivariable Cox proportional regression analysis

		Univariable analysis		Multivariable analysis	
		HR (95% CI)	*p* value	HR (95% CI)	*p* value
Clinical data	Age (years)	0.99 (0.97–1.01)	0.532		
	Gender	0.87 (0.39–2.87)	0.596		
	Diabetes	1.03 (0.55–1.91)	0.938		
	Hypertension	1.01 (0.56–1.79)	0.978		
	Smoker	0.96 (0.52–1.77)	0.906		
	Dyslipemia	1.21 (0.67–2.18)	0.530		
	NICM	2.59 (1.48–4.55)	0.001	2.84 (1.54–5.23)	0.001
	Stroke	1.68 (0.40–6.97)	0.475		
	COPD	1.53 (0.54–4.37)	0.427		
	CKD	1.84 (0.93–3.63)	0.082	6.15 (2.82–13.53)	< 0.001
	AF	3.55 (1.97–6.43)	0.001	2.78 (1.37–5.64)	0.004
	NYHA class	0.96 (0.38–2.45)	0.269		
	LBBB	1.04 (0.44–2.46)	0.928		
	Previous HF admission	1.31 (0.68–2.53)	0.417		
	QRS duration	1.01 (0.99–1.01)	0.911		
	LVEF	0.96 (0.91–1.01)	0.136		
	Beta blockers	1.51 (0.59–3.89)	0.398		
	ACEI or ARB	1.59 (0.69–3.64)	0.278		
	Aldosterone antagonists	0.94 (0.49–1.81)	0.849		
	Amiodarone	0.99 (0.30–3.28)	0.989		
ICD settings	VF detection zone cutoff > 188 bpm	0.99 (0.98–1.01)	0.818		
	30 of 40 intervals in VF zone	0.47 (0.26–0.88)	0.018		
	FVT programmed	0.54 (0.29–0.97)	0.038		
	FVT detection zone cutoff	0.99 (0.97–1.01)	0.510		
	Dual zone programmed	0.90 (0.51–1.59)	0.727		
	SVT limit > 200 bpm	0.97 (0.96–0.98)	0.001	0.24 (0.11–0.51)	< 0.001
	Onset	0.96 (0.40–2.29)	0.924		
	Stability	0.67 (0.37–1.20)	0.180		
	Wavelet	0.42 (0.19–0.93)	0.032		
	PR logic	0.28 (0.12–0.66)	0.004	0.18 (0.06–0.48)	0.001
	T-wave oversensing	0.05 (0.00–1.31 × 10^{15})	0.913		
	High-rate time out	0.04 (0.00–1.91 × 10^{7})	0.755		

ACEI, angiotensin-converting enzyme inhibitors; *AF*, atrial fibrillation at implant; *ARB*, angiotensin II receptor blockers; *bpm*, beats per minute; *CKD*, chronic kidney disease; *COPD*, chronic obstructive pulmonary disease; *FVT*, fast ventricular tachycardia; *HF*, heart failure; *ICD*, implantable cardioverter defibrillator; *LBBB*, left bundle branch block; *LVEF*, left ventricle ejection fraction; *ms*, milliseconds; *NCIM*, non-ischemic cardiomyopathy; *VF*, ventricular fibrillation

chamber devices were not related to a lesser risk of inappropriate shocks [15]. In all of the studies mentioned above, the ICD settings were not properly reported, especially regarding the algorithms used for SVT discrimination.

In our study patient selection, device choice and programming were not randomized but left to the physicians' choice. However, we tried to minimize the remaining potential bias by analyzing two weighted groups of patients programmed in the most homogeneous way. Although this approach may not solve all the possible bias, to the best of our knowledge, this is the first report of a primary prevention ICD recipient cohort without indication for pacing in which programming was collected and properly depicted and weighted. Our matched population was adjusted regarding clinical characteristics, but especially regarding the ICD settings. Despite a well-balanced programming, in our real-life nationwide cohort, the risk of an inappropriate shock was significantly lower with dual-chamber devices than single-chamber devices. Consequently, our findings may add important information to the real-life decision process.

The incidence of inappropriate shocks in our study is low, but it agrees with recent reports in which less aggressive programming was related to a decreased risk of all-cause shocks [5, 23]. Thus, current expert consensus on ICD programming recommends a high rate cutoff and delayed tachyarrhythmia detection duration for primary prevention HF patients [19]. In our study population, the cutoff rate within the VF zone was over 188 bpm in the vast majority of patients, but a delayed detection time (30 of 40 intervals) was only programmed in 38.1% of patients. This setting was related to a lower rate of inappropriate shocks in the univariable analysis but not after multivariable adjustment (Table 3). This may be explained because registry data were collected through a 9-year period in which scientific evidence was continuously evolving. Indeed, a delayed detection time within the VF zone was programmed in up to 79.1% of patients implanted beyond 2014.

In the multivariable analysis, patients with previous AF had a 2.7-fold increased risk of inappropriate shock, which is concordant with previous studies [14]. In addition, CKD and NICM independently predicted the occurrence of inappropriate shocks, with a 6.1-fold and 2.8- fold increased risk, respectively. These two clinical predictors have not been reported previously and suggest that patients with more comorbidities are at an increased risk of inappropriate shocks.

The dual-chamber tachyarrhythmia detection algorithm, PR logic, performs tachycardia discrimination in a stepwise process with the atrial and ventricular rate, pattern of atrial and ventricular events, ventricular cycle length regularity, atrioventricular dissociation, evidence of AF, and evidence of far-field R-wave sensing on the atrial lead. PR logic has been proven safe and accurate in several studies, focusing mainly on the technical performance of the algorithm [24–26]. However, data regarding the real world effectiveness of PR logic in primary prevention patients are poor. PR logic was used in dual-chamber devices included in the DATAS trial [11], but in this trial, the majority of implants were performed in secondary prevention patients, and dual-chamber ICDs failed to decrease the risk of inappropriate shocks. In Gold et al.'s trial [9], rhythm discrimination performed better in Medtronic devices than in Guidant devices, but no significant improvement in inappropriate shocks was seen with dual-chamber devices. Moreover, programming in this trial was not optimal, as a VT zone between 150 and 200 bpm was required and discriminators were available in this VT zone only, though 85% of patients were implanted as part of the primary prevention strategy. In a randomized trial, Friedman et al. [12] showed that dual-chamber ICDs with PR logic discriminator and optimal programming did not reduce the risk of inappropriate shocks in a small sample of primary prevention patients. In our study, the risk of inappropriate shocks was decreased by 81% using PR logic, and no other discriminator appeared to be independently related to fewer inappropriate shocks. No previous report has analyzed the independent role of SVT discriminators in preventing inappropriate shocks.

The SVT limit is an ICD setting that sets the fastest ventricular rate that can be identified as an SVT; thus, rhythms faster than the SVT limit are detected as VT/VF based only on the ventricular rate criterion. Recent reports support programming this setting at rates up to 230 bpm to prevent inappropriate shocks without delays in the detection of hemodynamically unstable VT [19, 27]. However, this setting has been considered a nominal parameter and not specifically analyzed. In our cohort, a 76% reduction in inappropriate shocks was seen in those patients with the SVT limit enabled to discriminate rhythms > 200 bpm.

The combination of PR logic and SVT limit > 200 bpm may have a stronger protective effect than each parameter separately, and our findings taken together can help physicians to optimize the settings of primary prevention ICDs already programmed with a single zone, high rate limit, and delayed detection time.

4.1 Study limitations

Conclusions extracted from our study are based on devices from only one manufacturer, and extrapolation to other brands should be made with caution. Moreover, the observational nature of the study allows some bias derived from patient and device selection. ICD programming has evolved throughout the last few years, and in our population, implants were performed over a 9-year period. We attempted to control for confounders using a PS-matched analysis, but some potential unmeasured confounders, such as the influence of reprogramming during the follow-up on the final results, cannot be assessed. This study attempted to assess whether dual-chamber discriminators are associated with clinical benefit (decrease in inappropriate shocks). However, we did not report nor evaluate the diagnostic efficiency of various SVT discrimination algorithms (sensitivity, specificity, and predictive values) because several reports have previously addressed this issue. A final limitation of this study is that procedure complications were not collected.

5 Conclusions

Inappropriate shocks are a frequent and undesirable effect in primary prevention patients implanted with a prophylactic ICD, despite programming high rate cutoffs and a long detection time. Patients with previous AF, CKD, or non-ischemic cardiomyopathy are at high risk of inappropriate shocks. Even after proper programming, dual-chamber ICDs are associated with a decreased risk of inappropriate shocks compared to single-chamber devices. PR logic emerged as a protective factor, as it is independently related to lower rates of

inappropriate shocks. Thus, the implantation of a dual-chamber device should be taken into account for primary prevention in HF patients who are at high risk of inappropriate shocks.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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