EUROPEAN SOCIETY OF CARDIOLOGY®

Europace (2008) **10**, 918–925
doi:10.1093/europace/eun146

Contribution of morphology discrimination algorithm for improving rhythm discrimination in slow and fast ventricular tachycardia zones in dual-chamber implantable cardioverter-defibrillators

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Received 23 January 2008; accepted after revision 11 May 2008; online publish-ahead-of-print 9 June 2008

KEYWORDS
Cardioverter-defibrillators;
Supraventricular tachycardia;
Ventricular tachyarrhythmias;
Morphology discrimination

Aims Morphology discrimination (MD) is an algorithm based on QRS morphology analysis, that can be used alone or in various combinations with other discriminators in order to diagnose ventricular tachycardia (VT) [the implantable cardioverter-defibrillator (ICD) may be set to diagnose VT if 'Any' or 'All' the discriminators indicate VT)].

Methods and results We evaluated the contribution of MD in terms of Specificity (SP) and Sensitivity (SE) of rhythm discrimination in slow and fast VT zones (rates <150 bpm and between 150 and 180 bpm, respectively). Detection results (682 spontaneous episodes in 58 patients) were corrected for multiple episodes within a patient (generalized estimating equations method). Rhythm discrimination in slow VT zones was characterized by SE and SP below 80% without MD, while the use of MD alone allowed to enhance SP, maintaining SE at 96%. Use of MD in combination with other discriminators resulted in a decrease in SP (setting 'Any'). In fast VT zones, MD allows an increase in SE for VT detection from around 82% up to approximately 94%, coupled with an SP of 95–96%., although SP is much higher with MD alone (94.8%) than with any other combination (78.4%). Both in slow and fast VT zones, use of multiple discriminators with the setting 'All' resulted in an unacceptable decrease in SE.

Conclusion MD in a dual-chamber ICD in combination with a rate branch classification system makes it possible to achieve a very high SP in discriminating detected events both in slow and fast VT zones, while maintaining SE for VT detection.

Introduction

The occurrence of inappropriate therapies of implantable cardioverter-defibrillators (ICD) is decreasing, thanks to the use of special algorithms that can correctly interpret patient rhythm. However, the improvements in device technology are still not completely able to prevent inappropriate therapies because of supraventricular tachyarrhythmias, which have been reported to occur in 11–41% of patients implanted with an ICD.[1–7] In order to reduce inappropriate device therapies for supraventricular tachyarrhythmias, algorithms for rhythm discrimination have been implemented in single- and dual-chamber ICDs.[1–21] Some studies reported clinical experience with discriminators using timing-based QRS analysis;[13–15] others are related to discriminators analysing QRS morphology.[16–20] In detail, discriminators based on duration and morphology of the ventricular electrograms (EGMs) have been evaluated both in single- [16–20] and dual-chamber devices.[8–11,19,20] While in single-chamber devices, the rhythm analysis is only based on the ventricular signal coming from the electrode positioned in the right ventricle,

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in dual-chamber ICDs atrial sensing provides additional information regarding cardiac rhythm, which may be analysed by dedicated algorithms resulting in a potential improvement of rhythm discrimination.[19,21] However, a recent prospective study[20] failed to demonstrate a significant advantage of dual-chamber ICDs over single-chamber ICDs in reducing the occurrence of inappropriate interventions.

Data reported in the literature on the importance of discriminating algorithms are not homogenous as rhythm discrimination has been applied to arrhythmias occurring in variable ranges of ventricular rates. The range of ventricular rates may *per se* influence sensitivity (SE) and specificity (SP) of any detection algorithm since a quite variable occurrence of sinus tachycardia is expected for rates below or above 140 bpm and a variable ratio of spontaneously occurring supraventricular/ventricular tachyarrhythmias is expected for rates below or above 140–150 bpm.[21] For these reasons in the present article, we decided to investigate rhythm discrimination of dual-chamber ICDs by means of an analysis that differentiates slow from fast ventricular tachyarrhythmias detection zones. In detail, in this study we analysed the SE and SP of rhythm discrimination using dual-chamber detection (rate branch) and QRS morphology analyses (morphology discrimination) in conjunction with other discriminators (sudden onset and stability) in a dual-chamber ICD during spontaneous arrhythmic episodes with specific importance to slow and fast ventricular tachyarrhythmia detection zones.

Methods

Patients

Fifty-eight patients (mean age 67 ± 11 years; 43 males and 15 females) implanted with a dual-chamber ICD (model Photon micro DR V-232, Atlas DR V-242, Epic DR V-233; St Jude Medical, Sunnyvale, CA, USA) were enrolled in this prospective study following informed written consent. The clinical profile of the study group (*Table 1*) was representative of a typical ICD patient population: three patients had right bundle branch block while no patient had left bundle branch block. No patient had evidence of rate-dependent bundle-branch block before ICD implant.

Table 1 Clinical data of enrolled patients

Number of patients	58 (43 male, 15 female)
Mean age $\pm$ SD (years)	67 ± 11
Clinical arrhythmia (no. of patients)	
Sustained VT	48
VF	4
Underlying disease (no. of patients)	
Coronary artery disease	39
Idiopathic dilated cardiomyopathy	10
Brugada syndrome	1
Hypertrophic cardiomyopathy	2
Right ventricular dysplasia	1
Valvular heart disease	3
Hypertensive heart disease	2
Antiarrhythmic drugs at implant (no. of patients)	
Beta-blockers	3
Sotalol	7
Amiodarone	36 (three with beta-blockers too)
None	15

VF, ventricular fibrillation; VT, ventricular tachycardia; AF, atrial fibrillation.

Patients with presumed necessity of high percentage of ventricular pacing at implanting, had physician evaluation excluded. Each ICD had been implanted in a subcutaneous or submuscular pocket in the left pectoral region and the leads were introduced transvenously. For atrial pacing/sensing, a passive or a screw-in bipolar lead was positioned in the right atrial appendage. A St Jude Medical ventricular lead (single- or dual-coil) was implanted transvenously for defibrillating and pacing/sensing the ventricle in all cases. At implantation, measurements of defibrillation thresholds, P and R wave amplitudes and slew rates, pacing thresholds and impedances yielded normal values. At the time of implant, 36 patients were receiving antiarrhythmic medications or beta-blockers. Antiarrhythmic treatment was not modified following ICD implant.

All the patients were requested to sign written, informed consent.

Rhythm discrimination algorithm characteristics and device programming

The implanted dual-chamber devices (manufactured by St Jude Medical) feature the programmable rate branch rhythm discrimination algorithm (*Figure 1*), which classifies the rhythm into one of the three branches based on the ratio between atrial and ventricular rates.[12,19,20] The three branches are: (i) ventricular rate slower than the atrial rate ($V < A$); (ii) ventricular rate equal to the atrial rate ($V = A$); (iii) ventricular rate greater than the atrial rate ($V > A$). Prior to rate branch classification, the device uses the Bigeminal avoidance (XE 'Bigeminal Avoidance') algorithm, which is based on an incremental/decremental counter active from the onset of the tachycardia intervals and implies a comparison between every detected cycle and the cut-off cycle for detection. According to the rate branch classification, a rhythm with the ventricular rate higher than the atrial rate ($V > A$ branch) is immediately classified as ventricular tachycardia (VT). For $V < A$ and $V = A$ branches, additional discriminators are needed to further analyse the atrioventricular relationship to prevent the with-holding of therapy during VT with the simultaneous presence of a supraventricular tachyarrhythmia. In the $V < A$ branch, an arrhythmia such as atrial fibrillation (AF) or atrial flutter is highly probable. To further aid rhythm discrimination of these supraventricular tachyarrhythmias from VT, additional Stability (IS) and morphology discrimination (MD) discriminators are used. In the $V = A$ branch, sudden onset (SO) and MD are used to discriminate between VT and supraventricular tachyarrhythmias such as sinus tachycardia. In this study, a standard value of 50 ms for the IS delta was used on the basis of previous experiences;[17–19] the nominal value of 12 intervals for the stability window size was used. For the SO delta, a nominal

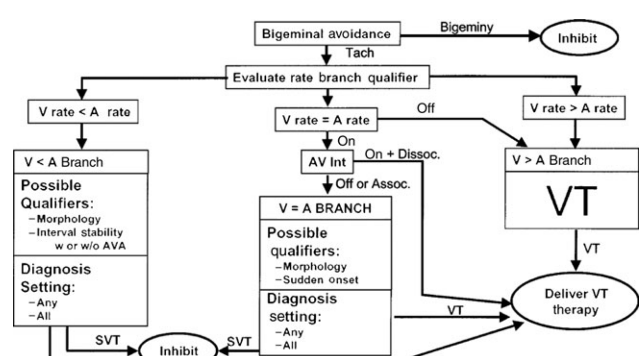

Figure 1 Rate branch algorithm scheme.

value of 100 ms was used. MD, used both in $V = A$ and $V < A$ branches, is a discriminator that compares the test QRS complex to a previously acquired stored template representing the patient's baseline rhythm on a beat-to-beat basis.[17,18] MD quantifies the difference between the corresponding peak areas of the test and template complexes[16–18] resulting in a similarity score. Complexes that have similarity scores greater than or equal to the user-programmable percent match threshold are considered to match the template. If the number of matches is less than the number required for the diagnosis of a supraventricular tachyarrhythmia, MD indicates the rhythm to be VT; otherwise MD indicates it as supraventricular arrhythmia. The QRS complex template was primarily acquired at implant. The device automatically checks the template every 8 h by comparing the stored template with the sinus rhythm complex and, if necessary, updates the template.

At patient discharge and during follow-up, device programming had to include: a monitor VT zone between 102 and 120–180 bpm (the cut-off was decided by the implanting physician and was 125–130 in six patients, 140–154 in 28 patients, 160–180 bpm in 24 patients) and an active treatment VT zone between the upper cut-off of the monitor zone and 210 bpm. Programming of the therapies was left to the attending physician, although the use of Pain-free like programming[22] was encouraged. Since the study was focused on algorithm performances at detection, no evaluation was performed on the effects of delivered therapies on detected arrhythmias, as well as on the detection after delivery of any therapy. The opportunity to change the cut-off rate and/or to programme the criteria for diagnosing a VT on the basis of 'All' or 'Any' of the discriminators indicating VT (see below) was left to the discretion of the investigators who decided during follow-up on the basis of the patient's clinical profile and previously detected arrhythmias.

After hospital discharge, routine follow-up was performed in all patients at 3-month intervals (3, 6, 9, and 12 month follow-up). After at least 1 month following implant, almost all patients performed an exercise test: 51 of 58 exercises tests were performed, seven not performed owing to inability of the patients to carry out the exercise test; 22 of 51 exercise tests were not evaluated as the spontaneous patient rate did not reach the 102 bpm cut-off (this may be owing to the use of beta-blocker drugs).

Analysis of rhythm discrimination on detected arrhythmic episodes

In the event of symptomatic arrhythmic episodes with or without ICD intervention, patients were instructed to contact our centre for additional device interrogation. For every spontaneous episode occurring in the low VT zone, printouts of stored ventricular EGMs (at 25 mm/s paper speed) were obtained, and the arrhythmia was then classified by two independent cardiologists. In all instances, in the event of discrepancy between the first diagnosis made by the two cardiologists, the EGMs were re-analysed and a final concordant common diagnosis was made. The performance of the discrimination algorithms was evaluated on the basis of the data stored in the device's memory, considering both possible programming settings of the tachycardia diagnosis criteria (i.e. 'Any' or 'All'). With the setting 'Any' for tachycardia diagnosis, the algorithm diagnoses the detected rhythm as VT if one of the discriminators indicates VT. With the 'All' tachycardia diagnosis criteria, every discriminator must indicate VT in order for the device to make a rhythm diagnosis of VT. SE and SP of the algorithm were evaluated according to traditional definitions.[18]

Data analysis

SP denotes the number of supraventricular tachyarrhythmias not correctly diagnosed as VTs/total number of detected arrhythmias that were clinically classified as supraventricular tachyarrhythmias.

SE denotes the number of diagnosed VTs/total number of detected arrhythmias that were clinically classified as VTs.

The generalized estimating equations (GEE) method has been used to correct the bias in the rate estimate because of the multiple arrhythmic episodes within the same subject. The GEE model was fitted by the GENMOD procedure of the SAS® system version 9.1.3, with an exchangeable correlation structure.

Results

During the follow-up phase of 19 ± 9 months (range 12–30), 682 spontaneous episodes with relative EGMs stored in the implanted device, occurring in the tachycardia zones were detected in 28 patients (332 in slow VT zone, 314 in fast VT zone, and 35 in VF zone, respectively).

The episodes were diagnosed as ventricular fibrillation (VF) in seven cases (1%, mean cycle length 241 ± 32 ms, min 195 ms, max 285 ms) occurring in four patients, VT in 82 cases (12%) occurring in 10 patients and supraventricular arrhythmia in 593 cases (87%). The latter occurred in 17 patients and included: AF in 37 cases (6%), atrial tachycardia (AT) in 110 cases (19%), sinus tachycardia (ST) in 443 cases (75%), and bigeminal rhythm in three cases (0.01%). All the supraventricular arrhythmias except one case of AF occurred in the slow or fast VT zone.

In all cases, both cardiologists were in agreement with the arrhythmia diagnosis. The performance of rate branch discrimination algorithm with and without the contribution of MD in the overall spectrum of detected VTs (slow and fast) is shown in *Table 2*. As shown, the contribution of MD in improving the specificity of rhythm discrimination is particularly relevant in ATs with regular ventricular rate. SP without MD appears quite low, improving only with the 'All' setting, although at the expense of a harmful decrease of SE in the latter case.

For our analysis on rhythm discrimination we also considered the two VT zones separately: slow VT zone (102–150 bpm) and fast VT zone (151–180 bpm). We excluded detected events faster than 180 bpm from the analysis of rhythm discrimination, as it is presumed that treatment of arrhythmias occurring in this range of frequencies (usually a defibrillation zone) is in any case required.

Rhythm discrimination in slow ventricular tachycardia zone

In the slow VT zone, 332 spontaneous episodes were detected, with 295 episodes diagnosed as supraventricular arrhythmias (444 ± 25 ms) and 37 considered as VT (453 ± 49 ms). In *Table 3*, SP and SE corrected by GEE analysis are calculated for all supraventricular arrhythmia types according to device diagnosis and physicians' confirmation and occurring in the slow VT zone (AF, AT, ST).

As shown in *Figure 2*, the overall SE for VT diagnosis in the slow VT zone was 96.0% (CI 72.7–99.5%) with tachycardia diagnosis criteria set to 'Any' and 77.2% (CI 40.9–94.3%) with the diagnosis criteria set to 'All'. Considering discrimination with MD only, SE was 96.0% (CI 72.7–99.5%) and was 77.2% (CI 40.9–94.3%) without MD. In the same way, SP varied according to the tachycardia diagnosis criteria setting, 'Any' or 'All', reaching, respectively, 77.2% (CI 42.0–94.1%) with 'Any' and 98.1% (CI 92.7–99.5%) with 'All'. Considering discrimination with MD only, SP was

Table 2 Performance of rate branch discrimination algorithm with and without the contribution of morphology discrimination considering all the arrhythmias detected in slow and fast ventricular tachycardia (VT) zones

Arrhythmia (type)	*n* patients	Any	All	MD only	Without MD
Specificity (SP)					
Atrial fibrillation	*n* = 23	16/23 (69.6%)	22/23 (95.7%)	22/23 (95.7%)	18/23 (78.3%)
	Patients = 7	SP_{GEE} = 68.9% (47.0–84.7%)	SP_{GEE} = 93.7% (62.3–99.3%)	SP_{GEE} = 93.7% (62.3–99.3%)	SP_{GEE} = 80.2% (72.1–86.4%)
Atrial tachycardia	*n* = 104	39/104 (37.5%)	98/104 (94.2%)	95/104 (91.4%)	42/104 (40.4%)
	Patients = 5	SP_{GEE} = 19.7% (2.9–66.5%)	SP_{GEE} = 92.5% (79.3–97.5%)	SP_{GEE} = 90.3% (78.4–96.0%)	SP_{GEE} = 25.7% (5.6–66.8%)
Sinus tachycardia	*n* = 442	437/442 (98.9%)	442/442 (100%)	438/442 (99.1%)	441/442 (99.8%)
	Patients = 12	SP_{GEE} = 98.0% (92.6–99.5%)		SP_{GEE} = 98.8% (92.9–99.8%)	SP_{GEE} = 99.7% (97.6–99.96%)
Overall*	*n* = 572	495/572 (86.5%)	565/572 (98.8%)	558/572 (97.6%)	504/572 (88.1%)
	Patients = 20	SP_{GEE} = 70.6% (50.9–84.7%)	SP_{GEE} = 97.1% (91.9–99.0%)	SP_{GEE} = 95.2% (88.7–98.0%)	SP_{GEE} = 79.6% (59.7–91.1%)
Without sinus tachycardia	*n* = 130	58/130 (44.6%)	123/130 (94.6%)	120/130 (92.3%)	63/130 (48.5%)
	Patients = 11	SP_{GEE} = 34.9% (15.7–60.7%)	SP_{GEE} = 93.5% (84.3–97.5%)	SP_{GEE} = 91.9% (83.7–96.2%)	SP_{GEE} = 53.7% (29.4–76.4%)
Sensitivity (SE)					
VT	*n* = 75	72/75 (96.0%)	63/75 (84.0%)	72/75 (97.3%)	63/75 (84.0%)
	Patients = 17	SE_{GEE} = 95.8% (87.3–98.7%)	SE_{GEE} = 80.2% (57.4–92.4%)	SE_{GEE} = 95.8% (87.3–98.7%)	SE_{GEE} = 80.2% (57.4–92.4%)

MD, morphology discrimination; SE_{GEE} denotes sensitivity (95% confidence interval) corrected by GEE analysis; SP_{GEE} denotes specificity (95% confidence interval) corrected by GEE analysis.
* Three episodes of 'Bigeminal avoidance' have been included.

98.1% (CI 92.7–99.5%), while SP fell to 77.2% (CI 42.0–94.1%) without MD.

Rhythm discrimination in the fast ventricular tachycardia zone

In the fast VT zone, 314 spontaneous episodes (one AF episode occurred in the 'VF' zone and it was not consequently analysed) were analysed with 276 supraventricular arrhythmias (376 ± 13 ms cycle length) and 38 VTs (366 ± 17 ms cycle length). In *Table 4*, SP and SE are shown for all detected events occurring in the fast VT zone, classified according to device diagnosis and physicians' confirmation and corrected with GEE analysis. As shown in *Figure 2*, the overall SE for VT diagnosis in the fast VT zone was 94.1% (CI 78.2–98,6%) with the setting 'Any', 82.1% (CI 56.1–94.3%) with 'All', 94.1% (CI 78.2–98.6%) with MD only and 82.1% (CI 56.1–94.3%) without MD.

The lowest SP values yielded during the study were for AT. All these cases of AT had a 1:1 atrioventricular conduction and were classified in the V = A rate branch. The highest SP values yielded in the study were for sinus tachycardia in both zones [97.0% (CI 89.7–99.2%) and 100% in the fast VT zone with 'Any' and 'All'; 100% with both settings in the slow zone], while for AF episodes were detected only in the fast zone—an SP of 64.9% (CI 40.4–83.5%) and 93.6% (CI 61.9–99.2%) according to 'Any' or 'All' settings, respectively.

Excluding all the episodes of ST from our analysis, SP in the slow VT zone decreased dramatically with 'Any' and 'without MD', while it remained at high values in the case of 'All' and with MD only [92.3% (CI 86.9–95.6%)]. In the fast VT zone, SP decreased in a similar way with 'Any' and 'without MD'. Considering the setting 'All' and MD only, SP reached 90.5% (CI 69.0–97.6%) and 89.2% (CI 68.5–96.9%), respectively.

Rhythm discrimination of events detected during the exercise test

Exercise tests were performed in 29 cases and the resulting ST was correctly classified in the V = A branch in 93% of cases while in two cases (7%) ST was incorrectly classified in the V < A rhythm branch, perhaps because of the ventricular far field on the atrial channel. Total SP, according to the 'Any' criterion, was set to 86.2% (25/29). In the case of 'All' discriminators required for VT diagnosis, 100% (29/29) of episodes were diagnosed as SVT, while MD correctly interpreted the rhythm in 93.1% of cases (27/29), the same value as without MD (93.1% with 27/29).

Discussion

Ventricular tachyarrhythmias may occur within a wide range of cycle lengths and in some cases VT may present slow ventricular rates. Slow VTs may occur in a substantial proportion of patients, especially after treatment with amiodarone or other antiarrhythmic agents (23,24), and programming a zone for VT detection and treatment at relatively slow rates enhances the probability of overlap between ventricular and supraventricular tachyarrhythmias or, even, ST. This usually results in difficulties in appropriate rhythm discrimination by the implanted ICD and may increase the number of inappropriate ICD therapies. On the other hand, as shown by

Table 3 Specificity and sensibility in the slow ventricular tachycardia (VT) zone according to the different types of detected arrhythmias

	Rate branch	*n* patients	Any	All	MD only	Without MD
Episodes of supraventricular tachyarrhythmias ($n = 295$) specificity (SP)						
Sinus tachycardia	V = A	$n = 239$	239/239 (100%)	239/239 (100%)	239/239 (100%)	239/239 (100%)
	MD = SO	Patients = 7				
Atrial fibrillation	V < A	$n = 1$	1/1 (100%)	1/1 (100%)	1/1 (100%)	1/1 (100%)
	MD+IS	Patients = 1				
Atrial tachycardia	V = A	$n = 54$	0/54 (0%)	50/54 (92.6%)	50/54 (92.6%)	0/54 (0%)
	MD + SO	Patients = 2		SP_{GEE} = 92.2% (86.8–95.6%)	SP_{GEE} = 92.2% (86.8–95.6%)	
Overall*		$n = 295$	241/295 (81.7%)	291/295 (98.6%)	291/295 (98.6%)	241/295 (81.7%)
		$n = 10$	SP_{GEE} = 77.2% (42.0–94.1%)	SP_{GEE} = 98.1% (92.7–99.5%)	SP_{GEE} = 98.1% (92.7–99.5%)	SP_{GEE} = 77.2% (42.0–94.1%)
Without sinus tachycardia episodes*		$n = 56$	2/56 (3.6%)	52/56 (92.9%)	52/56 (92.9%)	2/56 (3.6%)
		Patients = 4	SP_{GEE} = 49.6% (12.2–87.5%)	SP_{GEE} = 92.3% (86.9–95.6%)	SP_{GEE} = 92.3% (86.9–95.6%)	SP_{GEE} = 49.6% (12.2–87.5%)
Episodes of VT ($n = 37$) sensitivity (SE)						
VT with V = A MD+SO		$n = 13$	12/13 (92.3%)	10/13 (76.9%)	12/13 (92.3%)	10/13 (76.9%)
		Patients = 5	SE_{GEE} = 88.3% (44.4–98.6%)	SE_{GEE} = 68.2% (29.9–91.5%)	SE_{GEE} = 88.3% (44.4–98.6%)	SE_{GEE} = 68.2% (29.9–91.5%)
VT with V > A		$n = 24$	Discriminators are not active in this zone			
		$p = 4$				
Overall		$n = 37$	36/37 (97.3%)	34/37 (91.9%)	36/37 (97.3%)	34/37 (91.9%)
		Patients = 6	SE_{GEE} = 96.0% (72.7–99.5%)	SE_{GEE} = 77.2% (40.9–94.3%)	SE_{GEE} = 96.0% (72.7–99.5%)	SE_{GEE} = 77.2% (40.9–94.3%)

MD, morphology discrimination; SO, sudden onset; IS, interval stability; *n* denotes number of episodes; SE_{GEE} denotes sensitivity (95% confidence interval) corrected by GEE analysis; SP_{GEE} denotes specificity (95% confidence interval) corrected by GEE analysis.

* One episode of 'Bigeminal avoidance' has been included.

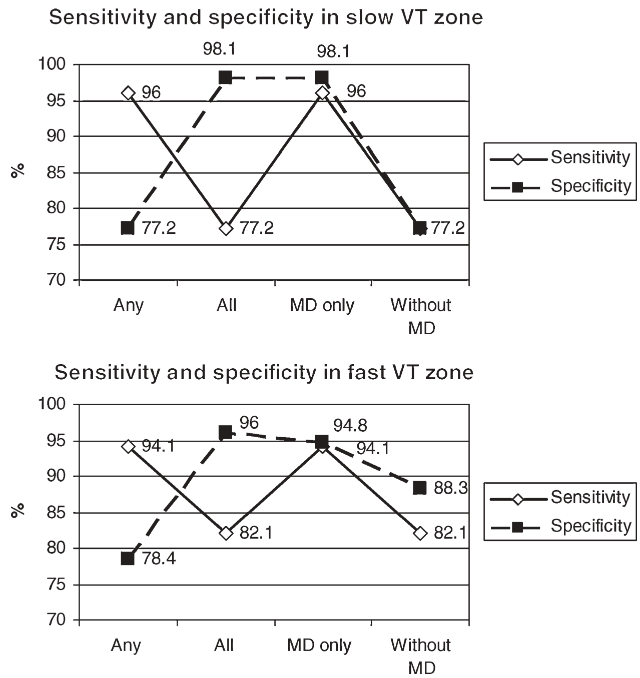

Figure 2 Contribution of morphology discrimination in improving rhythm discrimination in slow and fast ventricular tachycardia zone. Evaluation of sensitivity and specificity for different device diagnostic settings.

our study, extending VT detection to slow rate is clinically useful, as in our study the number of VTs occurring below 150 bpm was the same as those occurring between 150 bpm and 188 bpm. Thus, according to Bänsch *et al.*,[23,24] slow VTs appear to be a real and challenging problem with relevant clinical implications for daily practice (inappropriate interventions, lack of ICD interventions if the arrhythmia occurs out of the arrhythmia detection window).

It is noteworthy that broadening the tachycardia detection interval to relatively slow values may increase the tachycardia burden by more than three-fold.[24] In this condition, dual-chamber detection was reported to markedly improve rhythm discrimination in comparison with single-chamber detection.[24] However, the advantages of dual-chamber detection vs. single-chamber detection in terms of reducing inappropriate therapies and shocks are still a subject of debate. A very recent meta-analysis by Theuns *et al.*[25] showed that dual-chamber detection may reduce the overall number of inappropriate interventions, but not the number of patients experiencing this problem. In any case, the potential differences in SE/SP performance of a detection algorithm suggest differentiating slow from fast VT detection zones. Indeed, data reported in the literature on the importance of discriminating algorithms are not homogenous as discrimination has been applied to arrhythmias occurring in variable ranges of ventricular rates. The range of ventricular rates may *per se* influence SE and SP of any detection algorithm as a quite variable occurrence of ST is expected for rates below or above 140 bpm.[21] Moreover, a variable ratio of spontaneously occurring supraventricular/ventricular tachyarrhythmias is expected for rates below or above 140–150 bpm, also when the occurrence of other supraventricular tachyarrhythmias is taken into account.[21]

Various algorithms for enhanced rhythm discrimination have been proposed, either in single- or dual-chamber ICDs, with considerable variability from one study to the other with regard to design, type of tested algorithm, programming of the device, and burden of detected tachyarrhythmias.

Our study was planned to specifically analyse the discriminator capabilities of the MD algorithm with regard to slow and fast ventricular tachyarrhythmias, respectively, in a dual-chamber ICD. The results show that the overall performance of rhythm discrimination for ventricular tachyarrhythmias may benefit markedly from the use of MD. Overall, the implementation of MD in an ICD with atrial and ventricular sensing, in combination with a rate branch classification system, may obtain advantages in rhythm discrimination that may reach clinical significance: indeed, in slow VT zones, rate branch with the availability of MD allows to improve SP by maintaining SE at 96%. It is worthy to note that MD alone may result in a better performance than in combination with SO and IS (because of low SP of SO for ATs). In fast VT zones, MD allows an increase in SE for VT detection from around 82% up to approximately 94%, coupled with an SP of 95–96%, although SP is much higher with MD alone (94.8%) than with any other combination (78.4%).

The ability of rate branch, SO, and IS to correctly classify the detected rhythms was calculated with and without the contribution of MD. The net improvement in rhythm discrimination obtained by MD was particularly important in discriminating between VT and regular supraventricular tachyarrhythmias, such as AT, or, in some cases AF with limited beat-to-beat variations in ventricular cycle length.

The contribution of MD is also stressed by the data suggesting that for some discriminators such as IS, the performance is quite different according to the detection zones, being unsatisfactory for appropriately diagnosing supraventricular tachycardias and AF with ventricular rates faster than 150–170 bpm.[26]

It is noteworthy that in our study, the performance of SO (at the programmed value of 100 ms) appeared to be poor with regard to the appropriate discrimination of arrhythmia with 1:1 ratio between atrial and ventricular events. According to our study, the limitations of IS and SO suggest that the use of MD as the only discriminator could be a valid alternative to the use of SO and IS alone, or in combination with MD.

The use of discriminators based on the analysis of QRS morphology has been implemented in algorithms available both in the single- or dual-chamber ICDs. In single-chamber ICDs, the analysis of QRS morphology is integrated with a discrimination algorithm, which also involves sudden onset and stability discriminators.[18] A prospective study using morphology discrimination in dual-chamber ICDs showed a significant decrease in inappropriate detection in comparison with single-chamber programming, although this did not result in a reduction of inappropriate shocks.[20] As previously shown by our group, by others, and by the present study, the performance of the MD discriminator in a dual-chamber ICD is strongly dependent on the selected combination of applied discriminators.[19,27,28] In this study, programming rhythm discrimination with VT diagnosis based on 'All' the discriminators indicating VT is not advisable, as it may decrease SE $<80\%$.

Table 4 Specificity and sensitivity in the fast ventricular tachycardia (VT) zone according to the different types of detected arrhythmias

	Rate branch	*n* patients	Any	All	MD only	Without MD
Episodes of supraventricular tachyarrhythmias ($n = 277$) SP (specificity)						
Sinus tachycardia	V = A	203	198/203 (97.5%)	203/203 (100%)	199/203 (98.0%)	202/203 (99.5%)
	MD + SO	Patients = 8	SP_{GEE} = 97.0% (89.7–99.2%)		SP_{GEE} = 98.2% (90.4–99.7%)	SP_{GEE} = 99.3% (94.7–99.9%)
Atrial fibrillation	V < A	$n = 22$	15/22 (68.2%)	21/22 (95.5%)	21/22 (95.5%)	17/22 (77.3%)
	MD+IS	Patients = 7	SP_{GEE} = 64.9% (40.4–83.5%)	SP_{GEE} = 93.6% (61.9–99.2%)	SP_{GEE} = 93.6% (61.9–99.2%)	SP_{GEE} = 79.5% (68.6–87.3%)
Atrial tachycardia	V = A	$n = 50$	39/50 (78.0%)	48/50 (96.0%)	45/50 (90.0%)	42/50 (84.0%)
	MD + SO	Patients = 4	SP_{GEE} = 47.5% (11.8–86.0%)	SP_{GEE} = 87.5% (49.2–98.0%)	SP_{GEE} = 80.3% (37.9–96.5%)	SP_{GEE} = 55.6% (17.5–88.1%)
Overall*		$n = 277$	254/277 (91.7%)	274/277 (98.9%)	267/277 (96.4%)	263/277 (95.0%)
		Patients = 16	SP_{GEE} = 78.4% (60.2–89.7%)	SP_{GEE} = 96.0% (84.9–99.0%)	SP_{GEE} = 94.8% (85.8–98.2%)	SP_{GEE} = 88.3% (72.5–95.6%)
Without sinus tachycardia episodes		$n = 74$	56/74 (75.7%)	71/74 (96.0%)	68/74 (91.9%)	61/74 (82.4%)
		Patients = 10	SP_{GEE} = 49.6% (26.1–73.2%)	SP_{GEE} = 90.5% (69.0–97.6%)	SP_{GEE} = 89.2% (68.5–96.9%)	SP_{GEE} = 70.1% (46.1–86.5%)
Episodes of VT ($n = 38$) SE (sensitivity)						
VT with V = AMD + SO		$n = 9$	8/9 (88.9%)	1/9 (11.1%)	8/9 (88.9%)	1/9 (11.1%)
		Patients = 3	SE_{GEE} = 72.0% (18.6–96.7%)	SE_{GEE} = 28.0% (3.3–81.4%)	SE_{GEE} = 72.0% (18.6–96.7%)	SE_{GEE} = 28.0% (3.3–81.4%)
VT with V > A		$n = 28$	Discriminators are not active in this zone			
		Patients = 12				
Overall		$n = 38$	36/38 = 94.7%	29/38 = 76.3%	36/38 = 94.7%	29/38 = 76.3%
		Patients = 14	SE_{GEE} = 94.1% (78.2–98.6%)	SE_{GEE} = 82.1% (56.1–94.3%)	SE_{GEE} = 94.1% (78.2–98.6%)	SE_{GEE} = 82.1% (56.1–94.3%)

MD, morphology discrimination; SO, sudden onset; IS, interval stability; *n* denotes number of episodes; SE_{GEE} denotes sensitivity (95% confidence interval) corrected by GEE analysis; SP_{GEE} denotes specificity (95% confidence interval) corrected by GEE analysis.

* Two episodes of 'Bigeminal avoidance' have been included.

Conclusions

MD is an algorithm for discriminating VTs from supraventricular tachyarrhythmias on the basis of QRS morphology analysis. Overall, the implementation of MD in an ICD with atrial and ventricular sensing, in combination with a rate branch classification system, may produce advantages in rhythm discrimination that may reach clinical significance: indeed in slow VT zones, rate branch with the availability of MD allows to improve SP by maintaining SE at 96%. It is noteworthy that MD alone may result in a better performance than in combination with SO and IS (because of low SP of SO for ATs). In fast VT zones, MD allows an increase in SE for VT detection from around 82% up to approximately 94%, coupled with an SP of 95–96%, although SP is much higher with MD alone (94.8%) than with any other combination (78.4%). Both in slow and fast VT zones, use of multiple discriminators with the setting 'All' resulted in an unacceptable decrease in SE. Programming rhythm discrimination with VT diagnosis based on 'All' the discriminators indicating VT is not advisable since it may decrease SE $<$80%.

Acknowledgements

This clinical study was performed with the technical support of St Jude Medical Italia, Milan, Italy.

Conflict of interest: The authors thank Tiziana Guidotto from St. Jude Medical Italy for technical assistance. Paolo Silvestri is a St. Jude Medical Italia employee.

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