Diaphragmatic myopotential oversensing in pacemaker-dependent patients with CRT-D devices

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Aims To evaluate the incidence and clinical significance of diaphragmatic myopotential (dMP) oversensing in pacemaker (PM)-dependent patients with CRT-Ds.

Methods and results We retrospectively evaluated patients with CRT-Ds implanted at our institution between January 2000 and August 2006. PM-dependent patients were identified, and the incidence of inappropriate detections due to dMP oversensing and their possible clinical implications (inappropriate therapies, syncope, and death of any cause) were evaluated. CRT-Ds were implanted in 122 patients, 37 were or became PM dependent. During a mean follow-up of 22 ± 17 months, 7(18.9%) PM-dependent patients revealed inappropriate detections due to dMP oversensing. All oversensing episodes occurred in CRT-Ds with automatic gain control (AGC) sensing and integrated bipolar (IBP) leads in the RV apex. These detections led to inappropriate shocks in 2(5.4%) patients and syncope in 1(2.7%). Five (13.5%) patients died.

Conclusion dMP oversensing in PM-dependent patients with CRT-Ds is an important problem, particularly in CRT-Ds with AGC sensing and IBP leads, with over 20% of patients with these devices revealing inappropriate detections. The clinical impact of dMP oversensing is less marked but relevant, with both inappropriate therapies and syncope occurring in this small group of 37 patients and the possibility of related deaths.

Introduction

Owing to the growing population covered by current guidelines,[1] the number of patients with CRT-D devices is continuously increasing. These patients depend on their CRT-D device for the improvement of heart failure symptoms, if *responders* to this therapy; for the treatment of ventricular tachycardia and ventricular fibrillation (VF) episodes and for pacing, in the presence of bradycardia or AV block. Patients with CRT-D devices may in fact be pacemaker (PM)-dependent. Some patients have previous PMs that are up-graded to CRT-D systems and a significant number become PM dependent after an AV node ablation. Ablation of the AV node is performed in patients with rapid atrial fibrillation (AF), despite medical therapy, to ensure high-biventricular pacing percentages.

Oversensing is a well-acknowledged problem in the field of cardiac pacing and may occur with any PM or implantable cardioverter-defibrillator (ICD or CRT-D). A recent review of the overall incidence of ventricular oversensing in ICDs shows that 7.3% of patients with these devices experience oversensing episodes and 2.3% have inappropriate shocks.[2] The causes of ventricular oversensing are multiple and include electromagnetic interference, lead fracture or insulation break, P- or T-wave sensing and myopotential detection (pectoral, abdominal or diaphragmatic).[3] The first description of oversensing of muscle potentials associated with inspiration refers to a VVI PM with a unipolar ventricular lead,[4] but oversensing of diaphragmatic myopotentials (dMP) has also been described with bipolar leads.[5] The development of PM generators with programmable sensitivity allowed for the reduction of this problem.

With ICDs, the need to detect VF, characterized by electrograms of variable and sometimes small amplitude, invalidates the use of ventricular sensing with a fixed gain and threshold, an issue that has been resolved by the development of dynamic sensing with auto-adjusting sensitivity (AAS) and automatic gain control (AGC) algorithms. Dynamic sensing results in an increase of sensitivity

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throughout the cardiac cycle, diminishing the risk of VF undersensing, but creating the opportunity for dMP oversensing (particularly during slow heart rates, at the end of diastole, when sensitivity reaches its maximum).[6] Various reports of diaphragmatic oversensing with ICDs have been published,[7–12] and an association with bradycardia or ventricular pacing; sensing with AGC and integrated bipolar (IBP) leads has also been described.[11,12]

PM-dependent patients with CRT-D devices may be a particularly vulnerable group to dMP oversensing. The devices have dynamic sensing and consequently increased risk of dMP oversensing. The patients are PM dependent, and therefore continuously paced, a variable that has been associated with a higher risk of dMP oversensing.[11,12] And, being PM dependent, the risk of clinical consequences of PM inhibition during oversensing episodes in these patients is also increased. Taking this into account, the aim of this study was to retrospectively evaluate the incidence and clinical significance of dMP oversensing in PM-dependent patients with CRT-D devices.

Methods

We retrospectively evaluated all CRT-D systems implanted and followed at our institution between January 2000 and August 2006. CRT-D systems were programmed in accordance with patients' individual characteristics. In general, in patients in sinus rhythm, the device was programmed in DDD 55 bpm (or DDDR 55 bpm) with two tachycardia detection zones (ventricular tachycardia detection zone was set at 165 or 167 bpm and included antitachycardia pacing and defibrillation therapies, and VF zone was set at 200 bpm). In patients with permanent AF, the device was programmed in VVIR 60 or 70 bpm with identical ventricular detection zones. In the presence of AF with rapid ventricular rates, until these were controlled, ventricular detection zones were set at higher values (around 170–180 bpm for VT and 210 for VF). Ventricular sensitivity was maintained at nominal settings. Patients were re-evaluated 1 month after implantations and follow-up visits were scheduled every 4 months.

Of all CRT-D systems, those implanted in PM-dependent patients were identified. Patients were considered PM dependent if, during two consecutive visits, no R-wave was obtained with the lowest programmable pacing rate (30 bpm). Previous AV node ablation was registered.

CRT-D devices in PM-dependent patients were evaluated in terms of patients' demographic characteristics, type of generator (with AGC sensing or AAS sensing), type of right ventricular (RV) defibrillator lead [IBP or true bipolar (TBP)] and RV defibrillator lead positioning (RV apex or interventricular septum). The incidence of inappropriate arrhythmia detections due to oversensing of dMP was determined. Oversensing was attributed to dMP when lead failure was ruled-out during follow-up; oversensed signals were detected exclusively in the RV electrogram; presented high-frequency and low-amplitude characteristics, compatible with dMP; and were reproduced with Valsalva manoeuvres, forced inspiration and/or expiration. Clinically significant consequences of dMP oversensing were assessed and defined as inappropriate therapies and/or syncope due to this type of oversensing. Death of any cause was also evaluated, considering that in extreme cases, pacing inhibition and/or multiple inappropriate therapies (ATP leading to VF or multiple inappropriate shocks) due to dMP oversensing could, at least in theory, lead to death in this population of PM-dependent patients with low-ejection fraction and heart failure symptoms.

Results

Between January 2000 and August 2006, 127 CRT-D generators (including 5 replacements) were implanted in 122

patients at our institution. Of the 127 generators, 108 (85%) were Guidant/Boston Scientific generators with AGC sensing (Contak CD model 1823, Contak Renewal 2 model H155; Contak Renewal 4 models H190 and H195, Contak Renewal 4 AVT model M175, Contak Renewal 4 HE model H199, Contak Renewal 4 RF model H230 and Contak Renewal 4 RF HE H239), and 19 (15%) were Medtronic generators with AAS sensing (models 7272 InSync ICD, 7279 InSync III Marquis, 7298 InSync Sentry and C174AWK Concerto). Guidant/Boston Scientific generators with AGC were implanted with Guidant/Boston Scientific IBP defibrillator leads (models 0125, 0147, 0148, 0158, 0165, 0175, 0185), and Medtronic generators with AAS were implanted with Medtronic TBP defibrillator leads (models 6944, 6948, 6949). The majority of the defibrillator leads were positioned in the RV apex [only six (4.9%) of the 122 defibrillator leads were positioned in the interventricular septum].

Of the 122 patients with CRT-D systems, 37 were or became PM dependent during follow-up. Five had previous PMs that were up-graded to CRT-D systems (previous PM lead was extracted in only one) and 20 became dependent after an AV node ablation (performed in order to obtain high-biventricular pacing percentages in patients with rapid AF).

Table 1 shows the demographic characteristics, type of generator implanted, type of RV defibrillator lead implanted, RV lead positioning, response to resynchronization therapy, presence of appropriate therapies, and death in these PM-dependent patients.

During a mean follow-up of 22 ± 17 months, seven CRT-D generators in seven (18.9%) PM-dependent patients revealed inappropriate arrhythmic detections due to dMP oversensing (*Figures 1* and *2*). In one patient, these detections led to inappropriate shocks and in another, led to inappropriate shocks, and syncope (5.4% of inappropriate shocks and 2.7% of syncope). All oversensing episodes occurred in patients with AGC generators and IBP leads, and none had septal RV defibrillator leads (*Table 1*). In fact, in the group

Table 1 Demographic characteristics, type of generator (with AGC or AAS sensing), type of RV defibrillator lead (IBP or TBP), RV lead positioning (septal vs. apical), response to resynchronization therapy, presence of appropriate therapies and death in PM-dependent patients with and without dMP oversensing

	Without dMP oversensing	With dMP oversensing
Number	30	7
Male gender (%)	29 (97)	7 (100)
Mean age at implantation	68 ± 9 years	64 ± 8 years
Coronary artery disease (%)	24 (80)	5 (71)
Mean ejection fraction (%)	26 ± 7	23 ± 6
Atrial fibrillation[a] (%)	22 (59)	3 (43)
Generator with AGC (%)	26 (87)	7 (100)
IBP RV Lead (%)	26 (87)	7 (100)
Septal RV lead (%)	2 (7)	0 (0)
'Responders' (%)	24 (80)	5 (71)
Appropriate therapies (%)	13 (43)	2 (29)
Death (%)	5 (17)	0 (0)

Abbreviations: AAS, auto-adjusting sensitivity; AGC, automatic gain control; dMP, diaphragmatic myopotential; IBP, integrated bipolar lead; RV, right ventricular; TBP, true bipolar lead; PM, pacemaker. [a]Persistent or permanent atrial fibrillation at implantation or during follow-up.
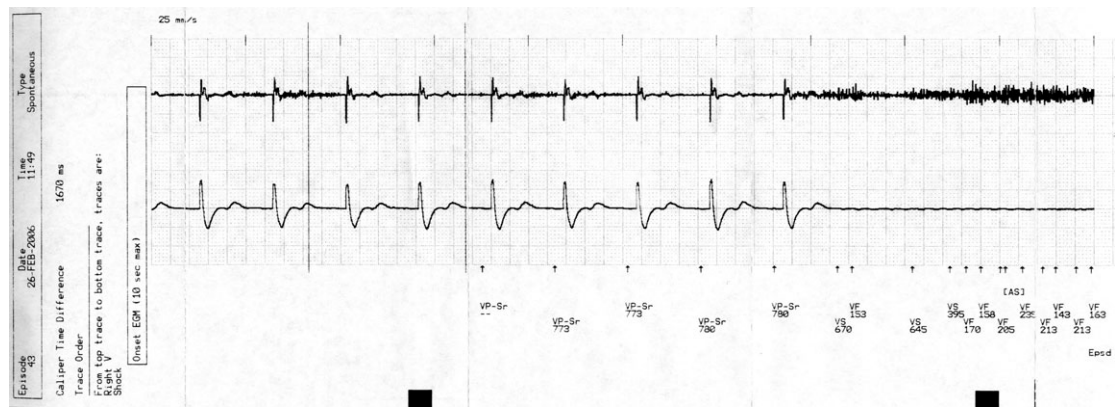
Figure 1 Oversensing of diaphragmatic myopotentials leading to inappropriate ventricular fibrillation detection: stored right ventricular, and shock electrograms (representative figure).
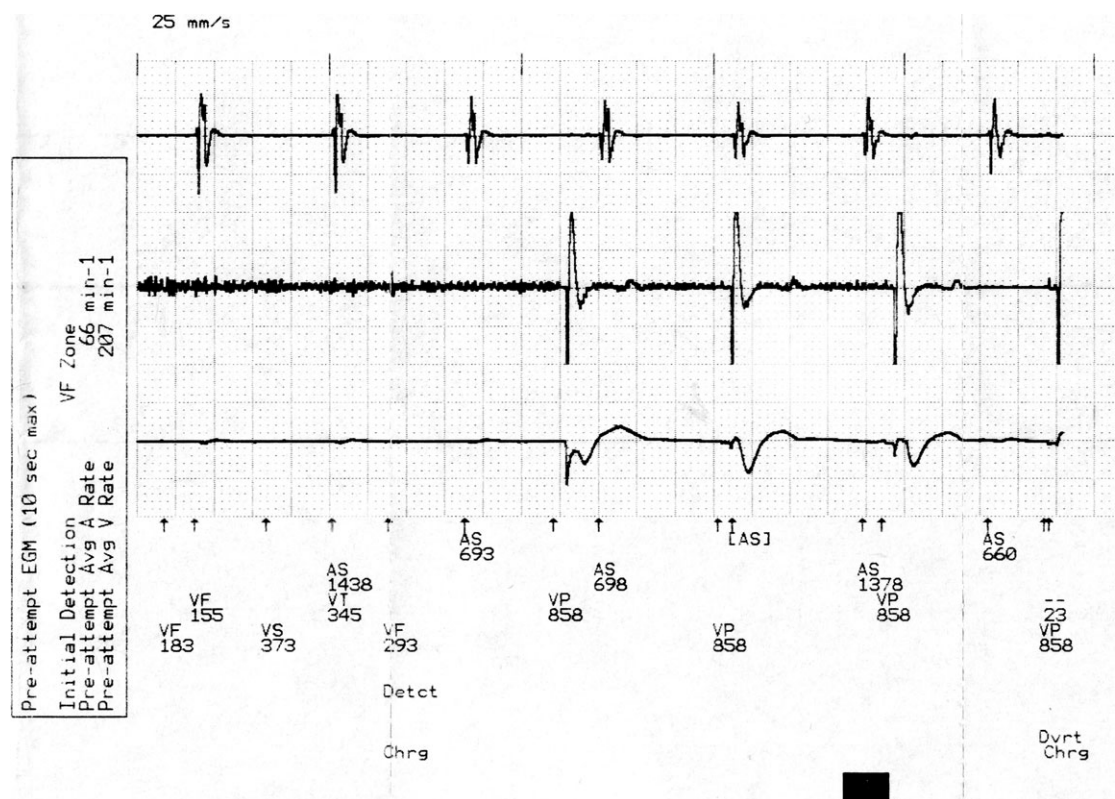
Figure 2 Oversensing of diaphragmatic myopotentials leading to inappropriate ventricular fibrillation detection and diverted therapy: stored atrial, right ventricular, and shock electrograms.

of patients with AGC generators and IBP leads (33 patients), the incidence of dMP oversensing was 21.2% (7 in 33).

During follow-up, five (13.5%) PM-dependent patients died (three from end-stage heart failure and two died suddenly). Of the two sudden deaths, one occurred in a PM-dependent patient, due to an AV node ablation, 32 months after implantation. *Post-mortem* device interrogation was not possible in this patient. The second sudden death occurred 1 month after implantation in a patient with a previous PM system that was extracted when the CRT-D was implanted. Interrogation of this device revealed no arrhythmic events. None of the five patients that died belonged to the group of seven patients with dMP oversensing (*Table 1*).

These results occurred despite systematic CRT reprogramming, in all patients with inappropriate detections due to

dMP oversensing, in order to minimize their occurrence. Alteration in CRT programming consisted in changing sensitivity to *least* (lowest programmable sensitivity in Guidant/Boston Scientific generators), after confirming adequate VF detection at this value. This change allowed for a reduction of the dMP oversensing episodes, but, in general, did not completely abolish them (*Figure 3*).

Discussion

In this specific group of PM-dependent patients with CRT-D devices, inappropriate detections due to dMP oversensing occurred in 18.9% of the patients and 5.4% had inappropriate shocks.
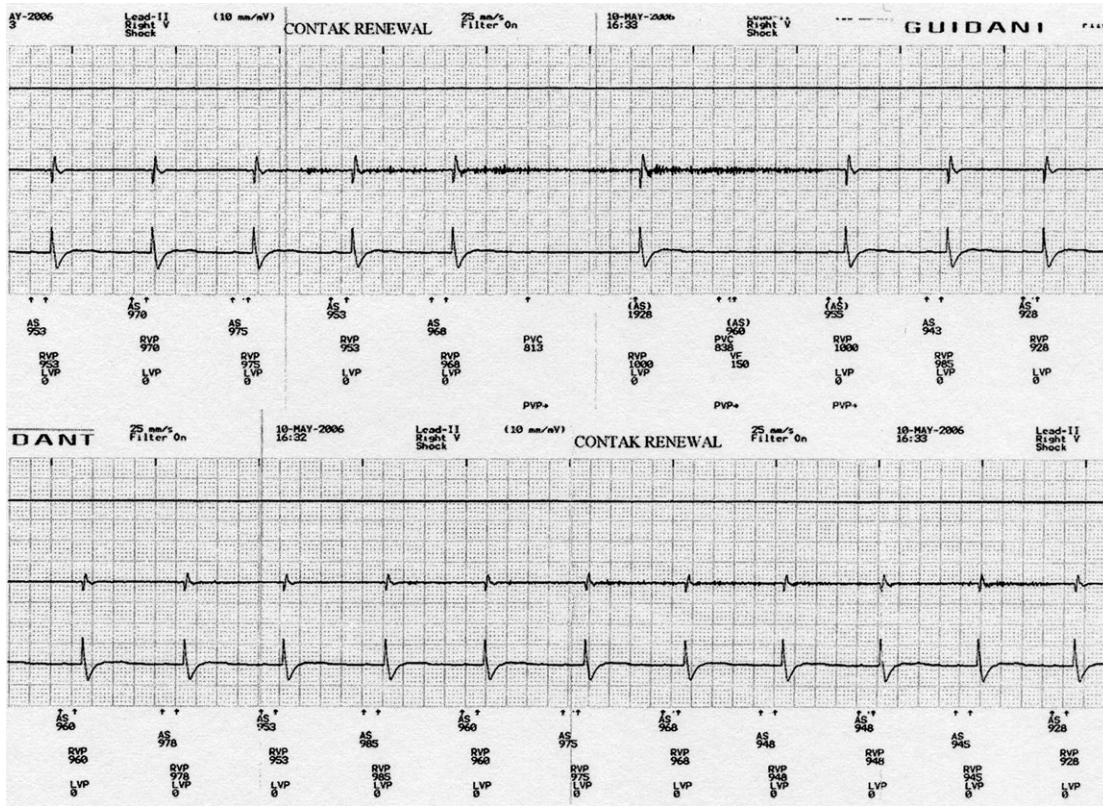
Figure 3 (Top) Diaphragmatic myopotential oversensing during Valsalva manoeuvre with sensitivity programmed in nominal: stored right ventricular and shock electrograms. (Bottom) Abolishment of oversensing during Valsalva manoeuvre with sensitivity programmed in least: stored right ventricular and shock electrograms.

Schulte *et al.*,[12] in a general population of ICD implantations, reported an incidence of inappropriate arrhythmia detections due to dMP oversensing of 8.6%, and a 3% incidence of inappropriate shocks. In another report by Rauwolf *et al.*,[2] only 1.5% of patients with ICDs had inappropriate detections due to myopotential oversensing (of the respiratory, trunk or upper arm musculature).

It is important to note that in the present study, as in the report by Schulte *et al.*, the vast majority of patients had defibrillator systems with AGC sensing and IBP leads.

In fact, in our group of patients, if we consider only the PM-dependent patients with CRT-D devices with AGC sensing and IBP leads (89% of the PM-dependent patients), the percentage of inappropriate detections due to dMP oversensing increases to 21%. In contrast, no inappropriate detections due to this type of oversensing were recorded in PM-dependent patients with generators with AAS sensing and TBP leads. However, the number of patients with this type of system is too small (four patients) for any conclusions in terms of the incidence of this problem in this subgroup or for any adequate comparison with the group with AGC devices and IBP leads. With this limitation in mind, it is still obvious that in those with AGC generators and IBP leads, the problem of inappropriate arrhythmia detections due to dMP oversensing is important and some studies do report a higher incidence of this complication with these devices and leads when compared with AAS generators and TBP leads.[11,12]

In the AGC algorithm, maximum sensitivity is obtained more rapidly and maintained for a longer period than with AAS algorithm. This is particularly true during pacing, since time-to-maximum sensitivity is linked to the pacing rate with AGC (and achieved 200 ms before the ventricular escape interval), but is independent of this rate in AAS systems. Owing to these inherent characteristics of the two algorithms, AGC allows a longer period of time in maximum sensitivity, particularly during pacing, thus increasing the risk of dMP oversensing.[11]

With IBP leads sensing occurs between the distal tip of the RV lead and the distal shocking coil, whereas TBP leads sense between two poles on the distal tip of the lead. This allows for a broader sensing area in IBP leads that could explain a higher incidence of inappropriate detections due to dMP oversensing in these leads, as determined in some reports.[11,12]

It is also important to note that the type of myopotentials evaluated in this study were considered diaphragmatic due to the characteristic high-frequency and low-amplitude signals observed in the RV lead, with no alteration in the shock electrogram, and their reproducibility during Valsalva manoeuvres, forced inspiration and/or expiration. It has been previously mentioned[13] that with IBP leads, inadvertent DF-1 connector inversion, at implantation, can also lead to oversensing, that could be misinterpreted as dMP oversensing. Distinction between these two types of oversensing is important, since their resolution differs, with DF-1 inversion requiring surgical correction of the DF-1 connections. When DF-1 connectors are inverted, RV sensing occurs between the distal tip of the RV lead and the proximal shocking coil/generator (as opposed to the distal tip of the RV lead and distal shocking coil), resulting in a quasi-unipolar type of sensing. With this inverted connection, upper limb or

thoracic myopotentials may be detected in the RV electrogram. However, these myopotentials present high-amplitude signals, are registered in the RV and shock electrograms and are reproduced with upper arm movements. In the oversensing cases of this study, the lack of interference in the shock electrogram and the low-amplitude of the detected myopotentials are important factors in ruling out DF-1 inversion (*Figures 1–3*).

Inappropriate arrhythmia detections due to dMP oversensing were relatively common, affecting one in every five PM-dependent patients with CRT-D devices, but were clinically significant in only a minority of patients: inappropriate shocks occurred in 5.4% of all PM-dependent patients (6.1% of those with AGC and IBP leads) and syncope occurred in 2.7% of all PM-dependent patients (3.0% of those with AGC and IBP leads). However, modification of CRT-D programming may have underestimated the real importance of this problem. In patients with dMP oversensing, sensitivity was systematically reduced, diminishing the number of oversensing episodes detected. Had we not altered this value, it is possible that the number of inappropriate shocks and syncope registered during follow-up would have been higher.

Assumption that pacing inhibition or inappropriate therapies due to dMP oversensing could in extreme lead to a patient's death, led to the determination of all cause mortality in this group of patients. If we compare the all cause mortality of this PM-dependent population (13.5% at a mean follow-up of 22 ± 17 months) to that of the CRT-D arm of the Companion study (all cause mortality rate of 12% at 12 months),[14] this population does not seem to have a worse outcome. However, two of the five deaths that occurred were sudden, the type of death that would be expected in a PM-dependent patient with pacing inhibition due to dMP oversensing. One of these patients died 32 months after CRT-D implantation; no previous oversensing episodes had been recorded, but *post-mortem* device interrogation was not performed, and thus dMP oversensing cannot be ruled-out as the cause of death. The second patient died 1 month after CRT-D implantation. In this case, the device was interrogated and did not reveal any arrhythmic event (true VT/VF or dMP oversensing recorded as VT/VF) since implantation, but one could still conceive the possibility of intermittent oversensing leading to PM inhibition without VT/VF detection allowing for the consideration of a serious adverse event as a consequence of dMP oversensing.

In conclusion, although several questions remain unanswered, PM-dependent patients with CRT-D devices have a high incidence of inappropriate arrhythmia detections due to dMP oversensing, particularly when generators with AGC and IBP leads are implanted. At the moment, dMP oversensing seems to be clinically relevant only in a minority of cases, but even in a small population of 37 patients followed for <2 years such episodes did occur. It is also fundamental to recall that death due to this type of dMP oversensing was not ruled-out. As the number of implants increases and follow-up lengthens it is therefore reasonable to expect an increased incidence of dMP oversensing and its clinical consequences. By taking these findings into consideration and acting accordingly, there is a possibility that we may avoid or at least diminish future problems. The best CRT-D option for PM-dependent patients is unknown. One approach to minimize dMP oversensing is to implant generators

without AGC sensing and TBP leads in these patients. Although this does not guarantee the absence of dMP oversensing, some reports do suggest that it is less frequent.[11,12] Another approach is to implant the RV defibrillator lead in the septum instead of the apex when using generators with AGC or IBP leads. In this study, none of the patients with septal leads had dMP oversensing, but again the number of patients with this type of defibrillator lead positioning is too small for conclusions. Provocative manoeuvres to test for dMP oversensing (such as Valsalva manoeuvres, forced inspiration, and/or expiration) could be instituted during implantation and follow-up. However, during implantation, the fact that these can only be tested with the patient supine may not exclude their presence with the patient sitting or standing. A fourth approach that we now use routinely during any CRT-D or ICD implant is to test VF detection during the defibrillation threshold tests with sensitivity programmed to its minimum, so that in the event of oversensing during follow-up, sensitivity can be lowered without further testing. Finally, when considering a patient for AV node ablation due to rapid AF, the type of CRT-D generator and lead should be ascertained and careful consideration should be given to the possibility of future dMP oversensing before performing the procedure. This caution seems particularly pertinent in light of a publication revealing similar left ventricular function and functional capacity improvement in patients with CRT in sinus rhythm and in AF, if AV node ablation is performed;[15] results that advocate for a wider use of AV node ablation in CRT-D patients, increasing the number PM-dependent patients at risk for dMP oversensing complications.

Limitations

Several limitations in this study should be stated. The study comes from a single centre and has a retrospective design. The follow-up period differs between patients. The vast majority of patients had CRT-D devices with AGC sensing and IBP leads as opposed to AAS sensing and TBP leads precluding an adequate comparison between these two groups, but emphasizing the importance of dMP oversensing in generators with AGC and IBP leads. Finally, due to the retrospective nature of this study, lack of a systematic archive of all evaluated non-sustained VT episodes and limited device memory (invalidating EGM storage and evaluation of all detected episodes in the event of very frequent detections), the true incidence of dMP oversensing may in fact be underestimated.

Conclusion

dMP oversensing in PM-dependent patients with CRT-D devices is an important problem, particularly when devices with AGC sensing and IBP leads are implanted, with over one fifth of these patients (21%) revealing inappropriate arrhythmia detections during follow-up. The clinical impact of dMP oversensing is less marked but relevant, with both inappropriate therapies and syncope occurring in this small group of 37 patients and the possibility of related deaths. Longer follow-ups, in larger populations, may be in the future reveal even greater clinical implications.

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