Preventing inappropriate shocks: Integrating ICD programming, drug and interventional treatment and jacuzzi avoidance

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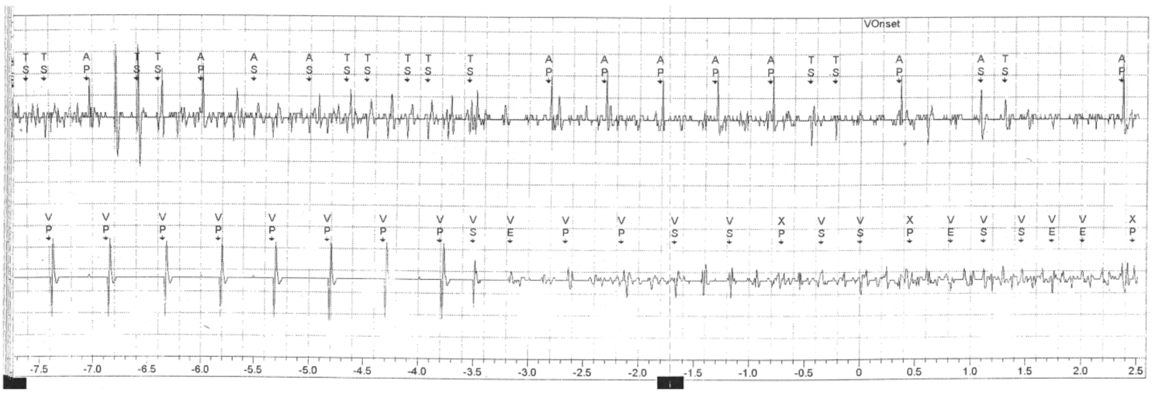
Case report

A middle aged female with hypertrophic cardiomyopathy underwent permanent pacemaker (PPM) implantation for tachy-brady syndrome with paroxysmal atrial fibrillation (AF). She subsequently suffered a syncopal event whilst driving.

Figure 1: A and V EGMs from PPM interrogation following syncope



<u>Question 1</u>

What does PPM interrogation (Fig 1) demonstrate?

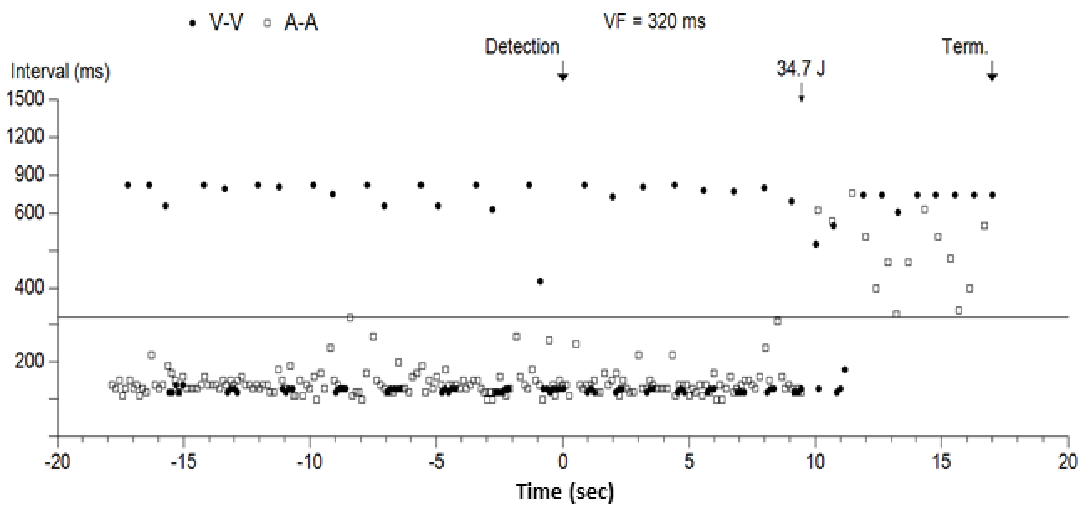
A Ventricular tachycardia (VT)
B Ventricular fibrillation (VF)
C AF with a fast ventricular response
D Noise on atrial (A) and ventricular (V) leads

Answer 1 = B

The A electrogram (EGM) shows fibrillation waves throughout. The V EGM initially shows ventricular pacing, followed by onset of VF, which appears to be initiated by a ventricular premature beat. The frequency is too high for a normally conducted ventricular response to AF. VT would have demonstrated a more organised ventricular rhythm on the V EGM. The frequency of EGM signals and mechanism of initiation with a ventricular ectopic is not typical for noise.

The patient underwent an upgrade to a dual chamber implantable cardioverter defibrillator (ICD). She remained well without therapies from her device until she received an unheralded shock whilst climbing out of a swimming pool. On interrogation all lead tests including impedance trends were satisfactory.

Figure 2: Interval plot of episode when shock was delivered



Question 2

What does the interval plot (Fig 2) demonstrate?

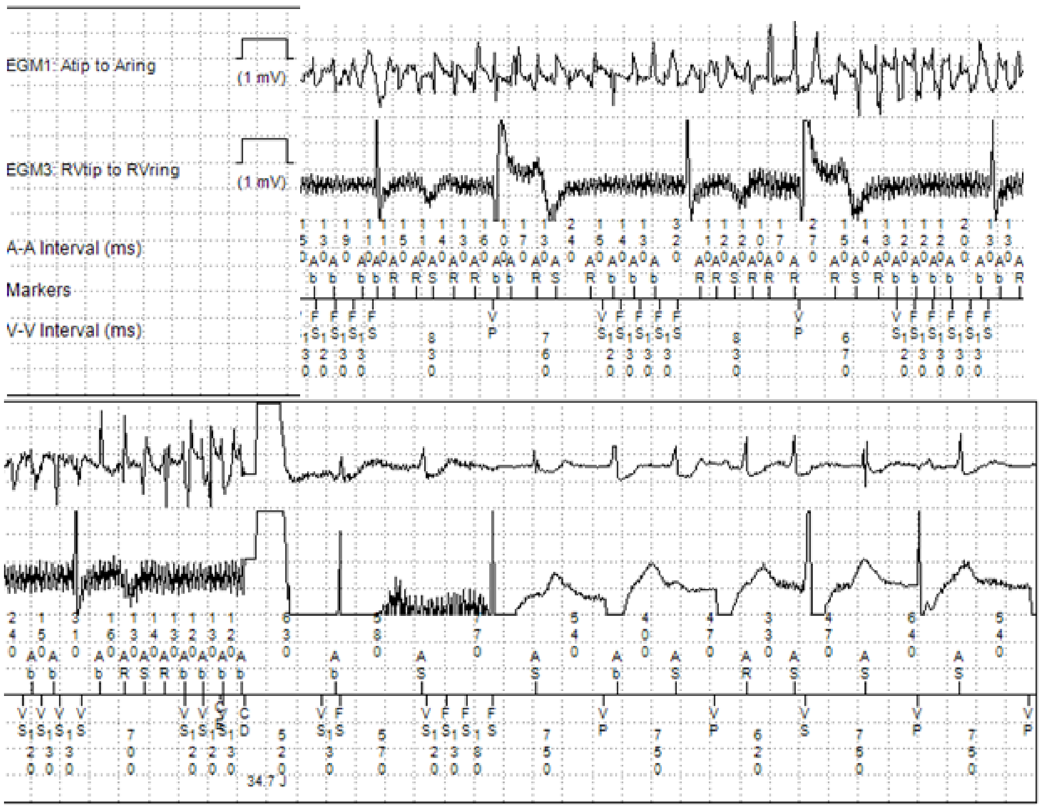
A VF
B VT
C Electromagnetic interference (EMI)
D Lead fracture

Answer 2 = C

The interval plot initially shows short A-A intervals consistent with AF, and V-V intervals at around 800ms, but with overlying recurrent brief episodes of short V-V intervals occurring regularly and at a constant frequency, most suggestive of EMI from electrical mains supply. VT would show regular intervals at around 300-400 ms and VF would show continuous chaotic intervals at around 200-300 ms. Lead fracture would be unusual with normal parameters and impendence trends.

EMI is confirmed on the EGM traces (Fig 3) which show fibrillation waves on the A channel and high frequency EMI on a background of normal QRS morphology on the V channel.

Figure 3: A and V EGMs of episode when shock was delivered



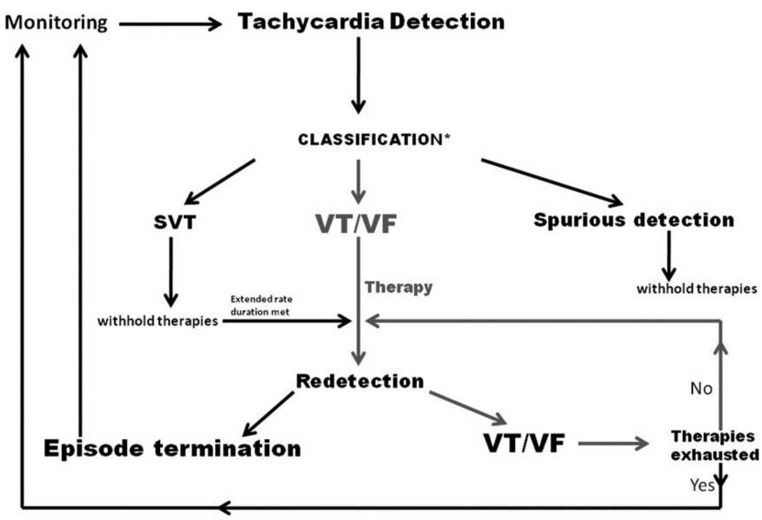
On further questioning, the patient remembered that on that day the adjacent jacuzzi had been on and testing confirmed an electrical fault. Jacuzzis have been described as possible sources of current leak, although this is the first description of resultant inappropriate ICD therapy as far as we are aware. Other water based EMI sources include swimming pools (1), showers (2) and pond pumps (3). Confirming lead integrity on device interrogation is helpful in distinguishing internal vs external sources of noise. The case highlights the importance of a detailed clinical history in identifying the exact source of EMI. ICD patients should be warned to avoid contact with potentially poorly earthed electrical equipment.

Reducing inappropriate shocks

Numerous studies show that ICDs confer survival benefit in patients at high risk of sudden cardiac death (4–8). However, despite technological advances, the incidence of inappropriate shocks, delivered for causes other than potential life-threatening VT or VF, remains high. This includes shocks for both SVTs and VTs which would have self-terminated without a shock. Inappropriate shocks are painful, psychologically disturbing and potentially arrhythmogenic (9–12). Recently, a subgroup analysis of two ICD clinical trials has shown an association between inappropriate shocks and increasing mortality (13,14). It is all too easy for physicians to think that their job is done once a device has been implanted, but careful attention to device programming and patient management can help physicians minimise the incidence of inappropriate shocks.

Figure 4 summarises the processes required for an ICD to deliver a shock. Sensed EGMs are processed by ICD algorithms including those for initial detection, SVT-VT discrimination and enhancements to minimize oversensing (15). If the rhythm is classified as a VT, depending on the programming, ATP may be delivered. The ICD then performs a redetection process to determine whether VT has terminated or continues. If VT is redetected, the process iterates until all programmed ATP is exhausted, when the device will charge its high-voltage capacitor. The ICD will then reconfirm that VT is present before delivering a shock.

Figure 4: Overview of ICD function. From detection of a tachycardia to its subsequent classification, various proprietary algorithms that use A and V rate, SVT discriminators and sensing enhancements operate. From Koneru et al (15).



Differentiation of SVTs from VT

Novel algorithms have been developed in order to aid differentiation of SVTs from VT. Optimal programming should be individualised according to the rate of clinical tachyarrhythmia and the likelihood of SVT occurrence in a given tachyarrhythmia zone. A lower clinical tachycardia cycle length will result in a higher relative percentage of VTs in comparison to SVTs (16). Discriminators should be activated in all patients without permanent complete AV block.

Single chamber discrimination algorithms from all major manufacturers are dependent on criteria of interval regularity, rate onset and V EGM morphology. Stability criteria help to differentiate VTs from episodes of AF with V rates within detection zones (17–21). They are however hampered by pseudo-regularization of the ventricular rate in AF with rapid V response (19,21). Irregular VTs such as PVT or irregular MVTs and ischaemic VTs with dynamic changes of the re-entrant circuit may also be problematic. Onset algorithms may be useful in excluding sinus tachycardia, where gradual acceleration of the ventricular rate is more likely to occur (17–20). However, this will not be useful for VT initiation during sinus tachycardia eg exercise induced VTs, and VTs that do not exhibit sudden onset (17,19,20). Overall, the combined use of stability and sudden onset criteria with time related override are associated with sensitivity 100% and specificity 83%.

Morphology algorithms may differentiate the origin of detected tachyarrythmia episodes through comparing the similarity of EGM morphology to a reference EGM template during supraventricular rhythm. Alone, this algorithm can result in sensitivity and specificity in range of 70-95 % (22–25). Care must be taken to avoid template misalignment or EGM truncation. Misclassification can also result from rate related aberrancy, or from VTs with a similar morphology to the intrinsic rhythm, eg septal VTs.

Dual chamber discrimination algorithms use timing and pattern of atrial events from the A EGM. There are different flow charts employed by different manufacturers (26). Generally the initial step is a comparison of V and A rates, as in over 90% of VTs the V rate will be higher than the A rate (27). Algorithms will next use comparisons of stabilities of V rate and A rates, and AV timings. If V and A rates are equal, they may also use single chamber discriminators. It is difficult to directly compare the specificity and sensitivities between manufacturers as trials have not been conducted head to head and have used differing cohorts of patients.

There is some debate over the relative performance of single vs dual chamber ICD discriminators. An A lead is clearly beneficial if the device is required for pacing or CRT with no AF (28); however an A lead may not be required solely for discrimination. Some studies have shown that dual chamber discriminators significantly reduce inappropriate treated episodes vs single chamber discriminators, but without significantly reducing the number of patients receiving inappropriate discharges (16,29,30); this may be due to a bias associated with a high contribution of a small number of patients to the total burden of inappropriate episodes (31). Dual chamber discriminators may paradoxically lead to tachyarrhyhmia misclassification due to atrial sensing errors; under-counting may result from prolonged or fixed atrial blanking periods and atrial event over-counting can result from far-field R wave sensing (32). We suggest that the addition of an A lead should be an individual decision, but is usually unnecessary solely for discrimination purposes.

Ventricular oversensing

Ventricular over-counting may occur for a number of reasons: T wave oversensing, electromagnetic interference, myopotential oversensing, sensing lead dysfunction and double QRS detection. Retrospective studies have shown that ventricular oversensing resulted in inappropriate shocks in 2-4% of pts with ICDs (33,34). T wave oversensing is relatively unusual given that ICDs now automatically adjust their sensitivity threshold; however it may occur in the setting of electrolyte abnormalities and or in the presence of drugs affecting the T wave. Sensing parameters should be adjusted where possible to avoid T wave oversensing in particular circumstances such as ARVC, sarcoid (low amplitude V EGM) and short QT Syndrome (tall T waves) and long QT Syndrome (long time from T wave to R wave).

Newer algorithms exist to detect lead noise oversensing through comparing the far-field and near-field EGMs. Alert features to trigger when lead impedence is out of a programmable range should be activated where available. EMI rejection algorithms may also be employed, but are more difficult to implement in ICDs than in PPMs as ICDs must be able to recognise the rapid rates of VF and therefore long blanking periods after sensed events are not feasible.

Therapy programming

The heart rate at which VT detection is set needs to be low enough to catch haemodynamically compromising VT, but high enough to reject most sinus tachycardia; a boundary of 330 to 300ms is usually sufficient. The tachyarrhythmia detection window should be prolonged by increasing the detection time. This has been shown to reduce the number of shocks with no under-detection of VTs or arrhythmic syncope (35).

There is some debate over the usefulness of ATP in reducing inappropriate shocks. Studies have shown that ATP successfully terminates ~90% of VTs with rates <200bpm with no significant problems with VT acceleration (36,37). The PainFREE Rx II trial used an 8 pulse burst which terminated 72% of fast VT (38). The EMPIRIC trial showed that programming ATP empirically reduced shocked episodes vs ‘tailored’ therapy, with no increase in VT acceleration or syncope (32). If nothing else, ATP prolongs the time to shock delivery, where SVTs or VTs may self-terminate. We suggest that multiple ATP programming should be employed in the VT zone < 200bpm, and at least one ATP sequence for monomorphic VT rates 200-250 bpm.

Pharmacological and interventional approaches

Beta blockers should be titrated to maximal tolerated doses to decrease the likelihood of the SVT rate falling within the VT/VF detection zones. Anti-arrhythmics may be employed to prevent SVTs and non-sustained VT. Amiodarone is most effective but has an adverse side effect profile. Catheter ablation should be considered for treatment of documented supraventricular tachyarrhythmias that may result in inappropriate shocks, especially those most amenable to ablation such as typical atrial flutter, AVNRT and AVRT. AV node ablation should be considered in the case of refractory arrhythmias. VT ablation may reduce the incidence of episodes of NSVT that could potentially result in shocks.

Conclusion

Many complex algorithms exist to minimise the risk of inappropriate shocks. New algorithms are constantly being developed, and future additions may include variability of the first post pacing interval between consecutive bursts (39), analysis of atrial response patterns during and after ATP (40), response of arrhythmia to simultaneous RA and V pacing (41), and atrial impedence amplitude during the cardiac cycle (42).

However, minimising ICD shocks requires good patient management on a number of levels, from patient selection to general medical care, including preventing electrolyte abnormalities, preventing ischemia and treating heart failure, the use of pharmacological and interventional therapy and choosing the appropriate device and algorithms for that individual. The EMPIRIC trial showed that empiric vs physician tailored ICD programming was associated with a lower percentage of SVT episodes resulting in shock with similar percentages of VTVF episodes results in shock (32). This might suggest that a 'one size fits all' policy should be adopted; however it may simply be a reflection of the fact that physicians may not have familiarity of the ICD parameters available. We would suggest that in order to best reduce inappropriate shocks, a detailed knowledge and use of all programming options is required, and that characteristics of each patient should be taken into account.

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