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CLINICAL REVIEW

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Cardiac implantable devices during exercise: Normal function and troubleshooting

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Abstract

Normal function and the most common problems that occur during pacemaker operation while performing physical exercise, are discussed. Physically active individuals with an implantable cardiac device, should be evaluated during exercise, because some conflicts issues may arise that are not detectable during routine, at rest, telemetry.

KEYWORDS

defibrillator, Exercise, Pacemaker, Telemetry

Highlights

Pacemaker function in patients able to perform physical activity, should also be evaluated while exercising, since some abnormalities can arise that are not detected at rest. Most situations that warrant diagnosis and treatment are related to the existence of an intrinsic cardiac rhythm Patients with tachyarrhythmia treatment devices, both atrial and ventricular, constitute the greatest challenge.

1 | INTRODUCTION

Implantable electronic cardiac devices such as pacemakers, resynchronizers, and cardioverter-defibrillators are indicated when the patient has bradycardia, intraventricular dis-synchrony or life-threatening ventricular tachyarrhythmias, respectively.[1-3] The device's functions must be carried out under different physiological (sleep, physical activity) or pathological states (fever, myocardial ischemia, hydro-electrolytic disturbances, drug effects), hence it is necessary that the device be carefully programmed and be able to perform its tasks under the circumstances above mentioned.

Usually, the evaluation and follow-up of patients carrying these devices takes place at the Outpatient Clinic at rest; however, those who are physically active, should be assessed while exercising, since during fast heart rates (intrinsic or paced), conflicts not previously detected, between the different refractory intervals and periods may improperly trigger diagnostic or therapeutic algorithms. Table 1 shows the most common problems and their approach, according to the parameter(s) to be programmed.

1.1 | Patients with sinus node disease

In patients requiring cardiac pacing due to sinus dysfunction or chronotropic incompetence, the "rate response" feature, mediated by activity, body temperature or myocardial impedance sensors should be programmed;[4,5] as well as an "upper rate limit"; and for the majority, "hysteresis of the atrioventricular (AV) interval" function is also turned on, in order to avoid unnecessary ventricular pacing[6-8] and maintain most of the time an AAI functional mode of stimulation (Figure 1A). The maximum stimulation rate, as well as the slope, both acceleration and deceleration, are chosen empirically, according to age; then, they are tested by monitoring the performance of the device during exercise.[9,10]

TABLE 1 Troubleshooting of stimulation and sensing pacemaker parameters during exercise

Clinical condition	Problem	Parameter to be programmed
Sick sinus disease	Low cardiac output associated with chronotropic incompetence	Rate response: maximum sensor rate, slope (gain), acceleration/deceleration time
	Unnecessary ventricular pacing	AV delay hysteresis algorithm
Complete AV block	Electronic Wenckebach AV block	Maximum tracking rate
Intermittent AV block or partially preserved AV conduction	False diagnosis of a supraventricular tachyarrhythmia or inappropriate automatic mode switch function	Maximum tracking rate Mode switching rate limit Automatic SAV/PAV interval adjustment Automatic PVARP adjustment
	Inappropriate antitachycardia pacing	Detection parameters of antitachycardia therapy
Frequent PVC during exercise	Unnecessary atrial stimulus after an undetected atrial event	PVC response algorithm
	Pacemaker-mediated tachycardia	PMT prevention algorithm
Congenital complete AV block	Escape junctional rhythm inhibits the pacemaker	Usually no intervention is necessary
Ventricular tachyarrhythmias	Inappropriate shock due to sinus tachycardia	Detection intervals for ventricular tachyarrhythmias SVT discrimination algorithms
Dyssynchrony due to LBBB	Loss of biventricular stimulation	SAV/PAV and VV intervals optimization RV and LV refractory periods Dynamic algorithms for resynchronization

Abbreviations: AV: atrioventricular; SAV: sensed AV interval; PAV: paced AV interval; PVARP: postventricular atrial refractory period; PVC: premature ventricular contractions; PMT: pacemaker-mediated tachycardia; SVT: supraventricular tachycardia; LBBB: left bundle branch block; RV: right ventricle; LV: left ventricle

1.2 | Patients with AV block

1.2.1 | Maximum tracking rate (MTR)

In patients who have preserved sinus function and have complete AV block, the most important parameter to take into account is the maximum tracking rate. [11,12] given that during dual chamber pacing, the atrium must be followed by ventricular stimulation (VAT pacing functional mode); as the sinus rate increases during exercise, a 1:1 AV ratio must be maintained until a maximum effort is reached; if the sinus rate exceeds the MTR, a mismatch or "electronic AV block" will occur, in which there will be more sinus depolarizations than those that device is capable of stimulate in the ventricle (Figure 1B,C; Figure 2);[13] the consequent sudden drop in heart rate and cardiac output at a given level of exercise, immediately produces symptoms, such as dyspnea or fatigue.

In patients who have a partially preserved AV conduction, different degrees of fusion with the patient's intrinsic beats can be observed (Figure 3A); if the patient has intrinsic Wenckebach-type AV block, the progressive prolongation of the AV interval can cause the subsequent atrial contraction to occur during the post-ventricular atrial refractory period (PVARP);[14,15] in these cases, errors can occur, such as a false diagnosis of a supraventricular tachyarrhythmias (Figure 3B), followed by inappropriate automatic mode switch function[16,17] and the subsequent loss of AV synchrony (Figure 4). In some patients with AV block, sinus node dysfunction occasionally may coexist and symptoms secondary to chronotropic incompetence are not recognized after pacemaker implantation; in them, is also necessary to turn on a rate response algorithm and a maximum stimulation rate limit, according to the physical performance of the patient.

1.2.2 | Adjustment of intervals and refractory periods

Most pacemakers have algorithms that progressively shorten the AV interval, according to the level of exercise of the individual, as well as the PVARP and the ventricular refractory period—the equivalent of the QT interval in the electrocardiogram, such as it happens under physiological conditions. Patients with paroxysmal or intermittent AV block, during exercise can achieve a fast sinus rate with adequate AV conduction; in these cases, it must be verified that a "mismatch" has not occurred due to any of these excessively long intervals[11,14-16] or, as it has already been mentioned, a false

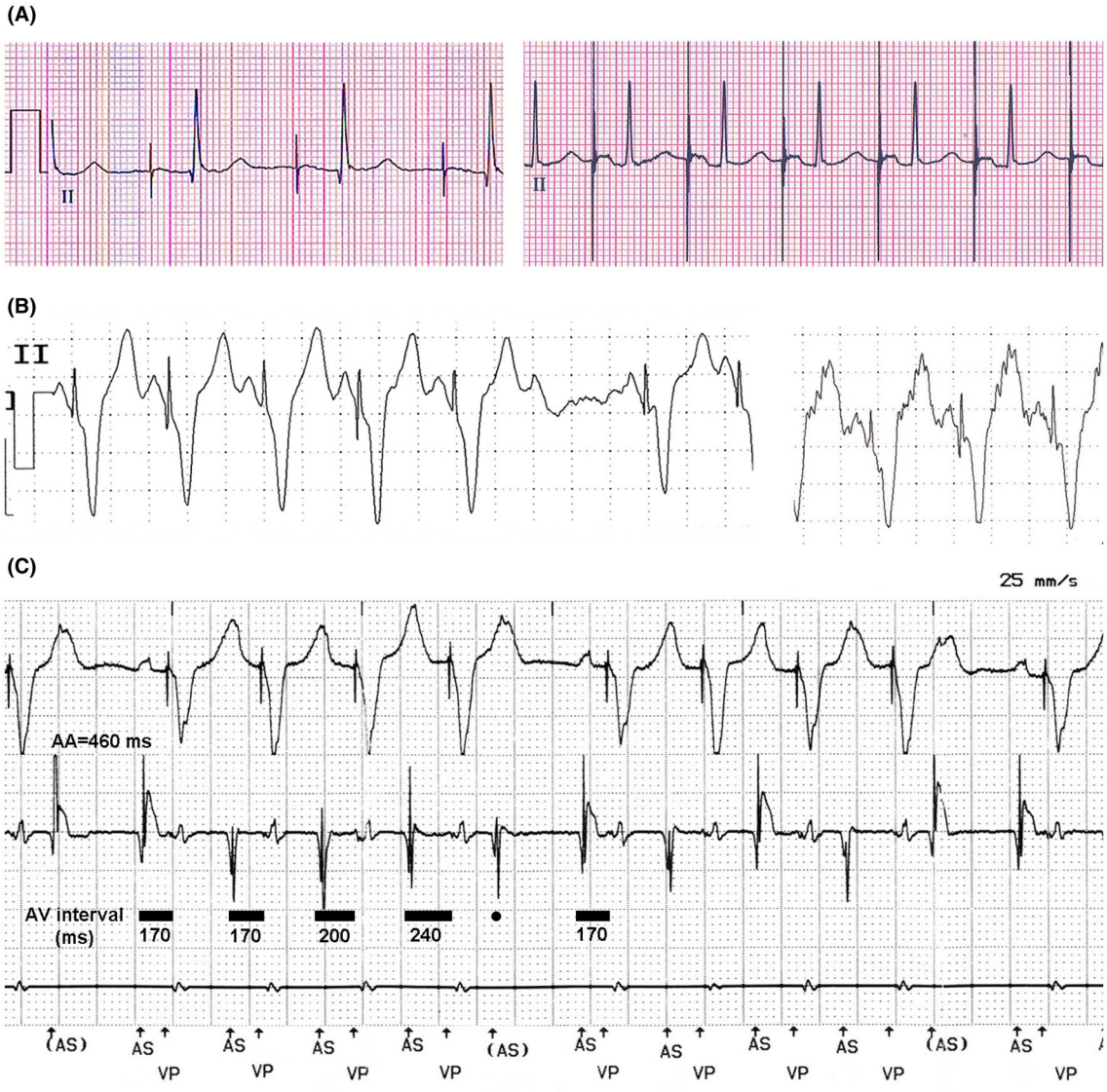

FIGURE 1 (A) Lead II. Pacing in AAI mode (atrial pacing—atrial sensing—pacing inhibition if atrial intrinsic activity is detected) at rest. Left: during exercise, the atrial rate stimulation increases, according to the level of activity developed by the patient, with the same AAI mode, due to the detection of intrinsic ventricular activation. (B) Lead II. VAT pacing functional mode (ventricular pacing—atrial sensing—triggering after a sensed atrial event) during physical exercise, 130 beats per minute (bpm); a P wave is observed that is not followed by ventricular pacing, because it has reached the Maximum tracking rate (MTR), a phenomenon called "electronic atrioventricular block". Left: after the adjustment of the MTR. (C) Lead II, atrial electrogram, AV intervals, ventricular electrogram, and markers. AS: atrial sensed event; VP: ventricular paced beat. During physical exercise, a sinus rate -AS- slightly higher than 130 bpm (sinus cycle = 460 ms, AA) is reached; the MTR was programmed at 130 bpm; as sinus rate increases, the pacemaker will not pace (VP) beyond the programmed MTR; consequently, the atrioventricular (AV) interval is progressively prolonged, until an atrial contraction (•) occurs during the postventricular atrial refractory period (PVARP), indicated with (AS); for this reason, it is not followed by ventricular stimulus and the Wenckebach sequence is restarted. This anomaly is corrected by increasing the MTR value according to the patient usual level of exercise; then, sequential dual chamber detection-stimulation is achieved until reaching maximum exercise

atrial tachyarrhythmia is misdiagnosed (Figure 4) or the automatic mode switch algorithm kicked in; or, in devices capable of treating atrial tachyarrhythmias, antitachycadia pacing is performed inappropriately.[16,18] Attention should be paid to these intervals, especially when the MTR has been already adjusted to the level of exercise the patient is capable of. Occasionally, device dysfunction may be detected only when the patient exercises;[19] in this case, the best possible programming will be sought to avoid its appearance.

1.2.3 | Effect of ventricular premature contractions (PVC)

Sometimes PVCs can have effects on pacemaker function that can lead to confusion and can be even more challenging during exercise. In the presence of a rapid sinus rate, once a PVC appears, the next atrial contraction can occur during PVARP (Figure 5) and it will not be tracked; even more so if the "response to PVC"

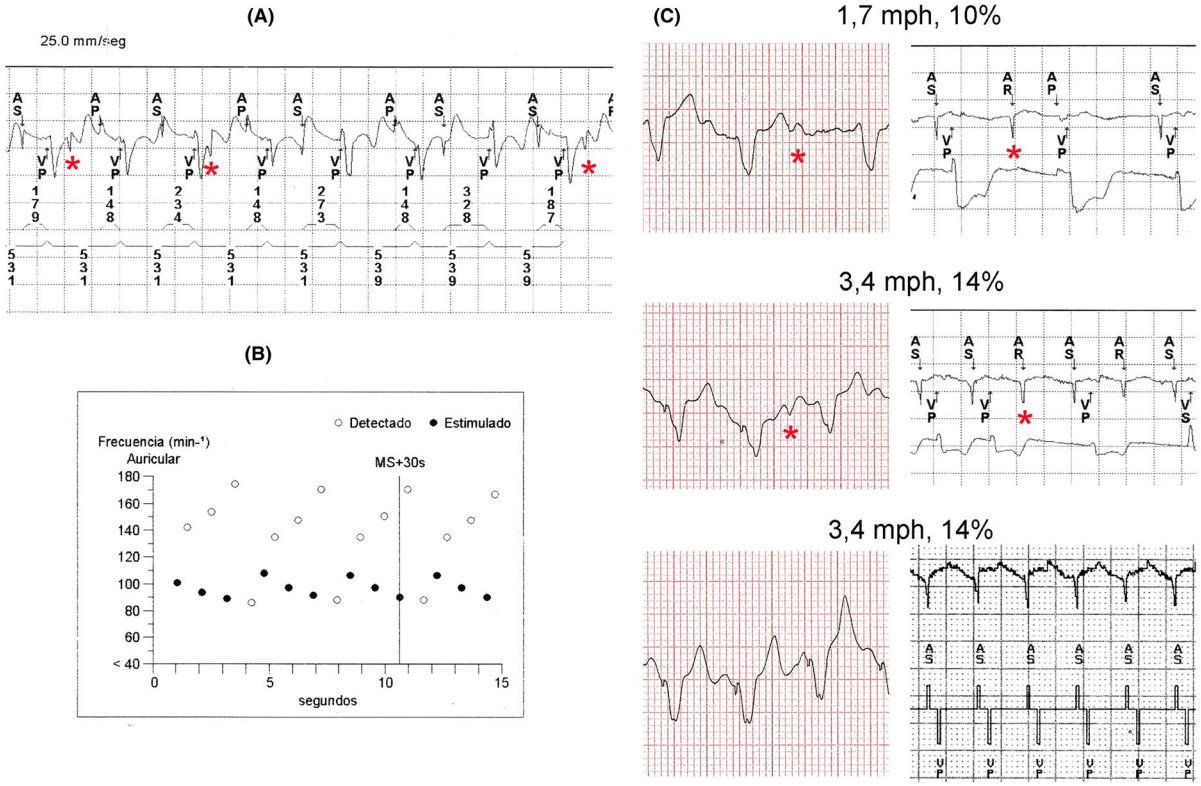

FIGURE 2 (A) Stored electrogram in the DDD pacemaker of a patient with congenital complete AV block; a sinus rate of 160-170 beats per minute is observed and several atrial contractions (AS) appear during PVARP (*); therefore, they will not be followed by ventricular pacing nor will they be taken into account for the delivery of the next atrial spike (AP), giving a geometric appearance of the plotting graph (B). (C) During stress test under Bruce's protocol, as soon as the exercise started, P waves without QRS were observed due to the same phenomenon; simultaneous telemetry shows an atrial event detected during the PVARP (AR); MTR was adjusted according to the level of effort achieved, until 1:1 AV conduction was obtained

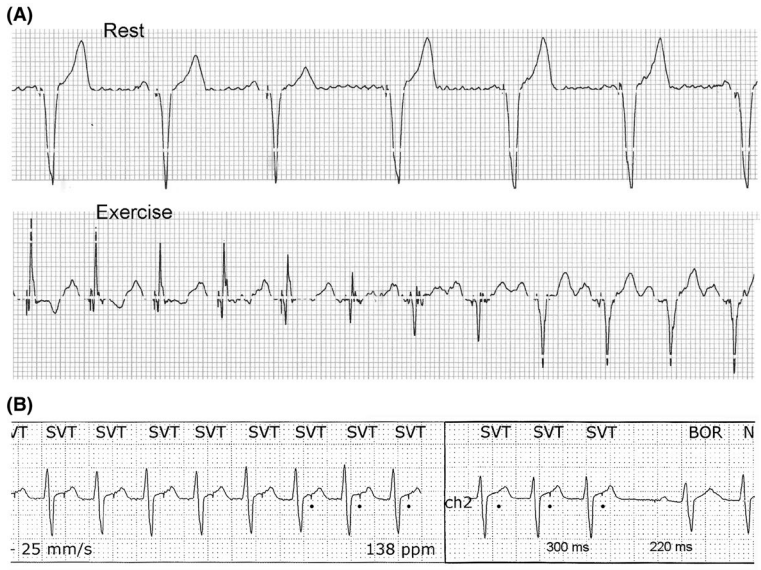

FIGURE 3 (A) Lead II. DDD pacemaker in a patient with intermittent atrioventricular (AV) block, VAT pacing functional mode; the second and third paced QRS complexes are narrower, indicating some degree of fusion with the intrinsic ventricular rhythm; during exercise, the initially stimulated QRS complexes are narrow, which also indicates that they are fusion beats; due to the underlying AV conduction disorder, these complexes gradually widen, indicating the prevalence of pacing over the intrinsic rhythm. (B) Holter recording. During physical activity, AAIR pacing mode is observed, 138 bpm; atrial spikes are indicated with (•); erroneously it was classified as "supraventricular tachycardia" (SVT); on the right, an atrial spike is not followed by an intrinsic QRS complex; the preceding AV interval (300 ms), compared to the subsequent one (220 ms), indicates that the patient has an intrinsic Wenckebach AV block

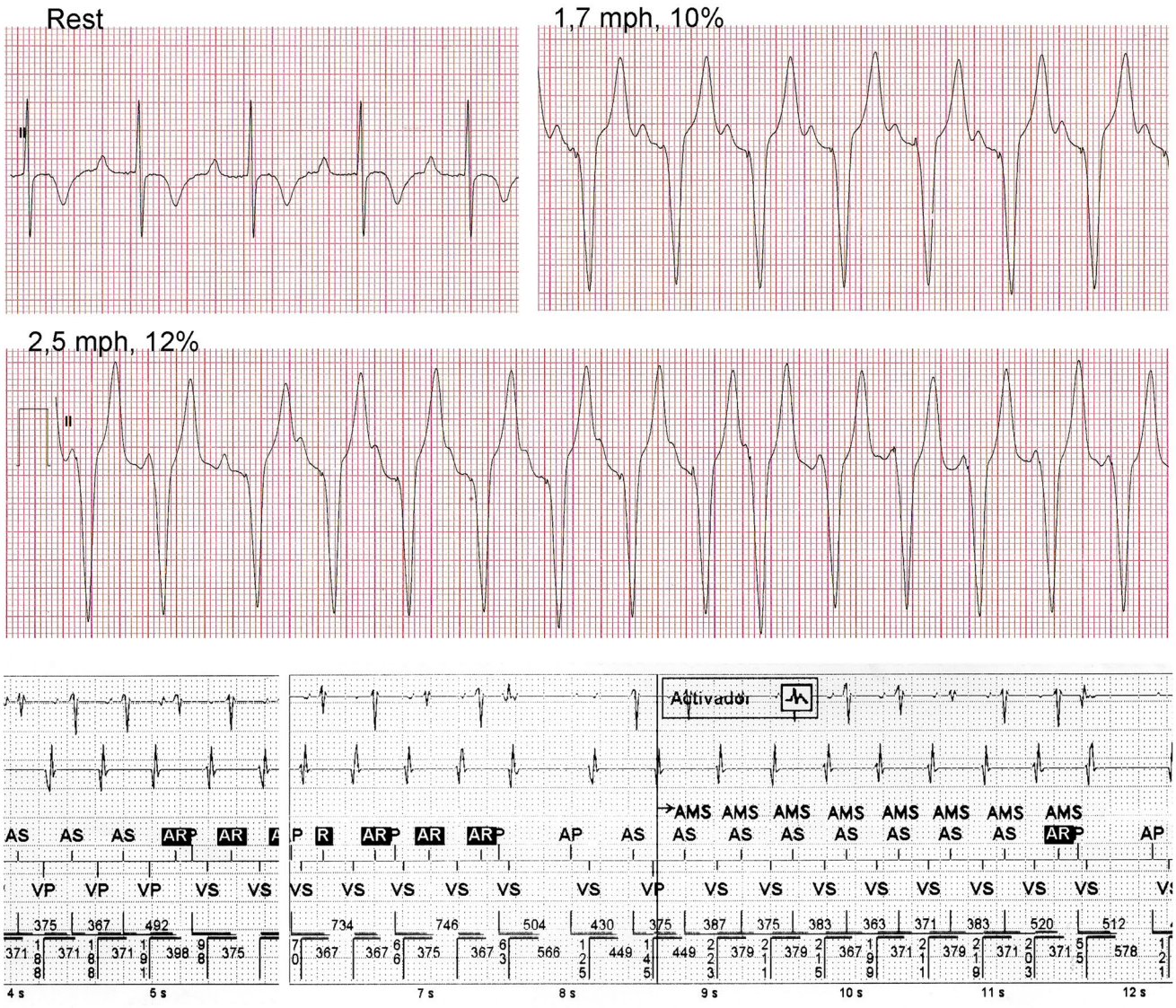

FIGURE 4 A patient with variable degree AV block and DDD pacemaker. At rest, first degree AV block, PR = 0.26 s; during the beginning of the exercise under Bruce's Protocol, the pacemaker switched to VAT pacing functional mode, in view of his underlying conduction disorder; but during the second stage, a "lag" is observed between atrial contractions and paced ventricular beats. During simultaneous telemetry interrogation (bottom), sinus beats are seen to be enrolled during PVARP (AR); they are ignored by the detection circuit, then the pacemaker sends stimuli (AP) that "resets" the sinus node and, finally, sinus tachycardia restarts; this is erroneously interpreted as an atrial tachyarrhythmia and the automatic mode switch (AMS) algorithm changes to DDI mode inappropriately

algorithm has been programmed, in which a longer duration of the PVARP is intentionally prolonged; in some cases, this atrial contraction will not be taken into account and the pacemaker can send an unnecessary atrial stimulus; the same can happen if there is ventricle-atrial conduction and eventually a pacemaker-mediated tachycardia can be induced.[20] Rarely, a PVC can cause the myocardium not to quickly regain its excitability and some spikes do not produce the respective ventricular depolarization, despite the fact that the threshold test was normal during assessment at rest (Figure 6).

1.3 | Young adult patients with congenital complete AV block

In absence of other congenital anomalies, the device was implanted for symptomatic bradycardia, in the majority of these patients. During physical exercise, they frequently have a chronotropic increase in their junctional escape rhythm of narrow QRS complexes;[21] the pacemaker initiates pacing in VAT functional mode, but typically in the vicinity of maximum exercise, the junctional escape rhythm inhibits the pacemaker, causing an abrupt fall of the heart rate and the

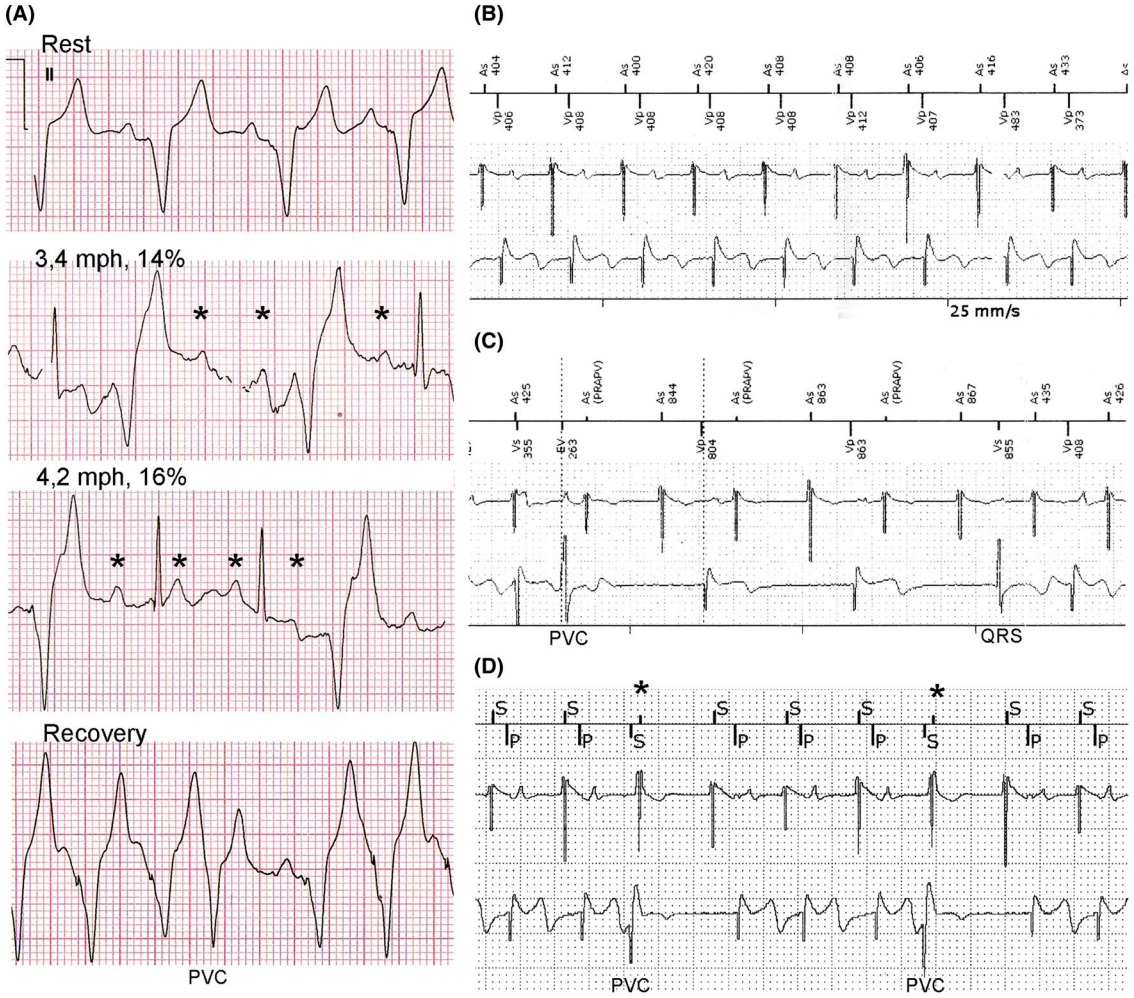

FIGURE 5 (A) Stress test under Bruce's protocol in a young patient with congenital complete AV block. Lead II. VAT stimulation mode; during exercise, AV junction beats (narrow QRS complexes) are observed, dissociated from sinus rhythm (*), which intermittently inhibits ventricular pacing. (B) Simultaneous telemetry interrogation shows VAT pacing mode, at the start of exercise; paced AV interval = 140 ms (C). (A) ventricular premature contraction (PVC) causes the next sinus beat to be ignored; at this time, the pacemaker executes its AV interval hysteresis algorithm; it ends with detection of a junctional beat (QRS) and pacing resumes; in the last beat, the paced AV is 240 ms, because it depends on the MTR. (D) On recovery, VAT 1:1 stimulation mode was resumed; some PVC are interpolated; subsequent sinus contractions (*) appear during PVARP; therefore, they are not followed by QRS complexes

cardiac output, which is perceived by the patient, limiting its physical performance (Figure 7).

1.4 | Exercise in patients with implantable cardioverter-defibrillators

According to the clinical condition, physical exercise plays an important role in cardiac rehabilitation; particularly in some young patients with normal chronotropic function in whom moderate exercise is indicated, the challenge of assuming all the aforementioned scenarios without coming into conflict with the "zones" destined for the diagnosis of ventricular tachycardia or fibrillation, is added. The maximum range of heart rate desired in a physically active patient, must be carefully weighed against the limit, above which, the physician wants the device to diagnose and execute its functions, in order to prevent inappropriate therapies or proarrhythmic effects (Figure 8).[22,23] It is necessary to carry out a stress test in order to evaluate the physical condition of the individual, the maximum heart rate reached, and eventually, the appearance of arrhythmias, given that they must be taken into account as criteria for individualized programming; since young patients reach sinus rates around 160-180 bpm, so the first diagnostic zone is usually programmed above this value; the risk of inappropriate delivery of exercise-induced shocks in young patients is frequently associated with sinus tachycardia;[24] while in older patients with heart failure, it is more common to observe atrial fibrillation or other mechanisms not related to physical exercise. In patients who also have a biventricular stimulation device, the greatest challenge is avoiding loss of resynchronization, in the context of an elevated heart rate related to physical exercise.[16,25]. In such cases, careful adjustment of the sensed/paced AV intervals, VV intervals and right/left ventricular refractory periods

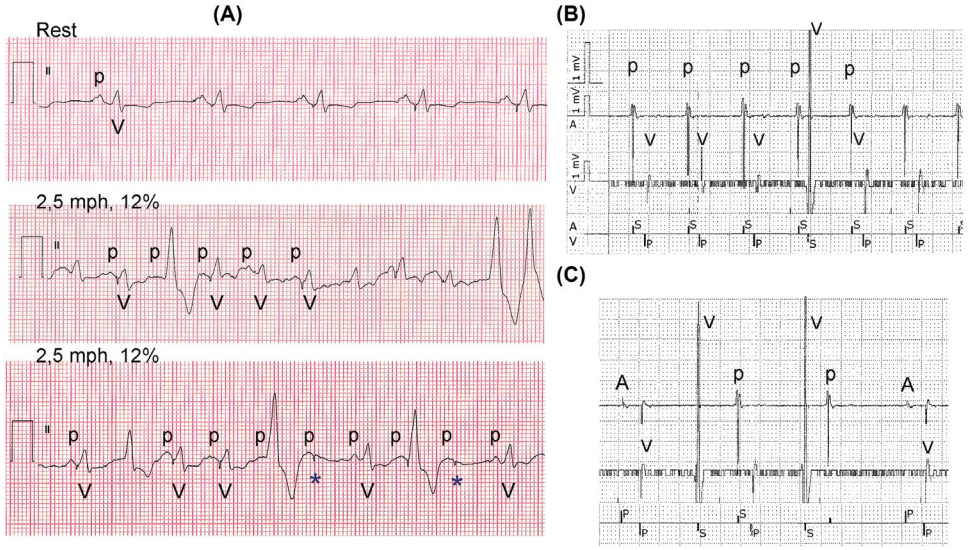

FIGURE 6 Patient with complete AV block and a DDD pacemaker; sensed AV interval = 160; VAT mode of stimulation. (A) Lead II; p: sensed P waves; V: ventricular paced beats. Stress test under Bruce's protocol; during exercise, frequent PVCs appear; some P waves followed by spikes with apparent loss of ventricular capture (*) are observed, possibly due to refractory ventricular tissue. (B) Electrograms A, V and markers recorded during the test. A PVC (V) appears at an interval shorter than the programmed AV interval; ventricular pacing is inhibited (S in the marker channel) and then, pacing is restarted in VAT mode. (C) The first PVC is detected (V), it is followed by a sinus beat (p) and its respective ventricular pacing (S, P in the marker channel); the second PVC is followed by a possibly retrograde atrial contraction (p), which occurs during PVARP; therefore, it is not followed by a ventricular stimulus

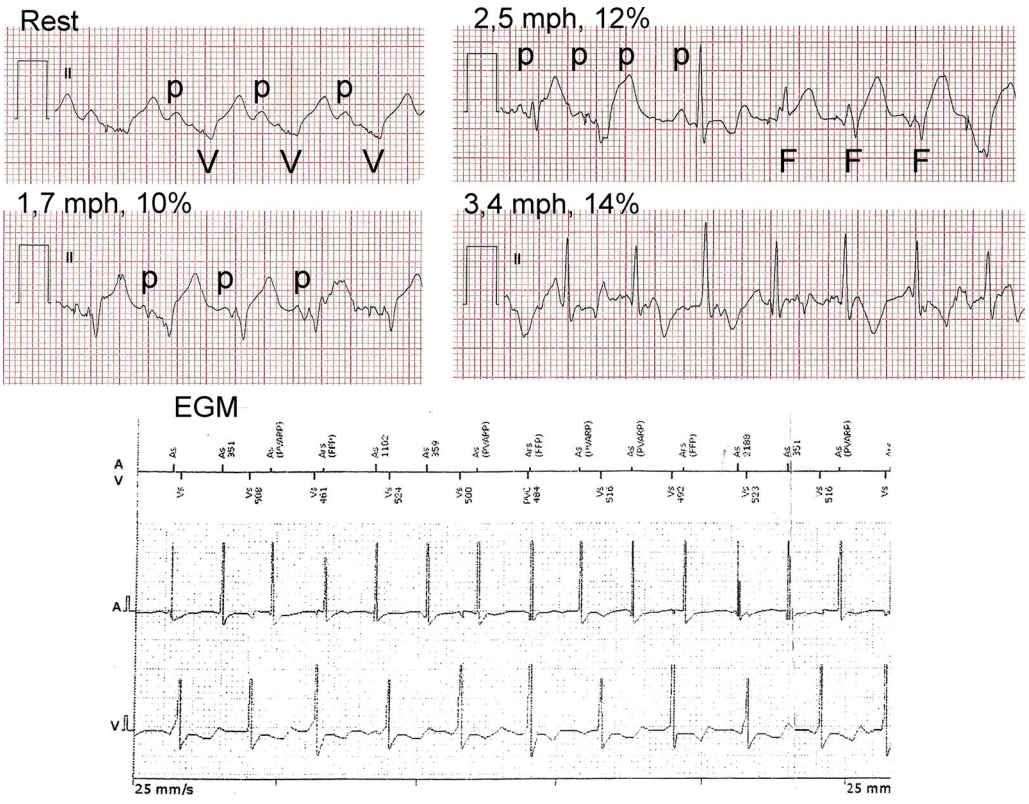

FIGURE 7 Exercise test under Bruce's protocol in a 42-year-old woman with a DDD pacemaker implanted due to congenital complete AV block. Lead II. At the beginning of the exercise, the stimulation mode is VAT (P: sensed P event; V: ventricular paced beats); during the second stage, AV junction beats fused with paced beats (F) are seen; during maximal effort, a narrow QRS junctional rhythm inhibits the pacemaker. This phenomenon was stored in the device (EGM), in which an atrial rate (As) faster than the ventricular rate is observed, as a consequence of the ventricular pacing inhibited by the junctional rhythm (Vs); both chambers are dissociated due to AV block; for this reason, some ventricular beats are sensed during the PVARP or are labeled as "far field R waves" (FFP)

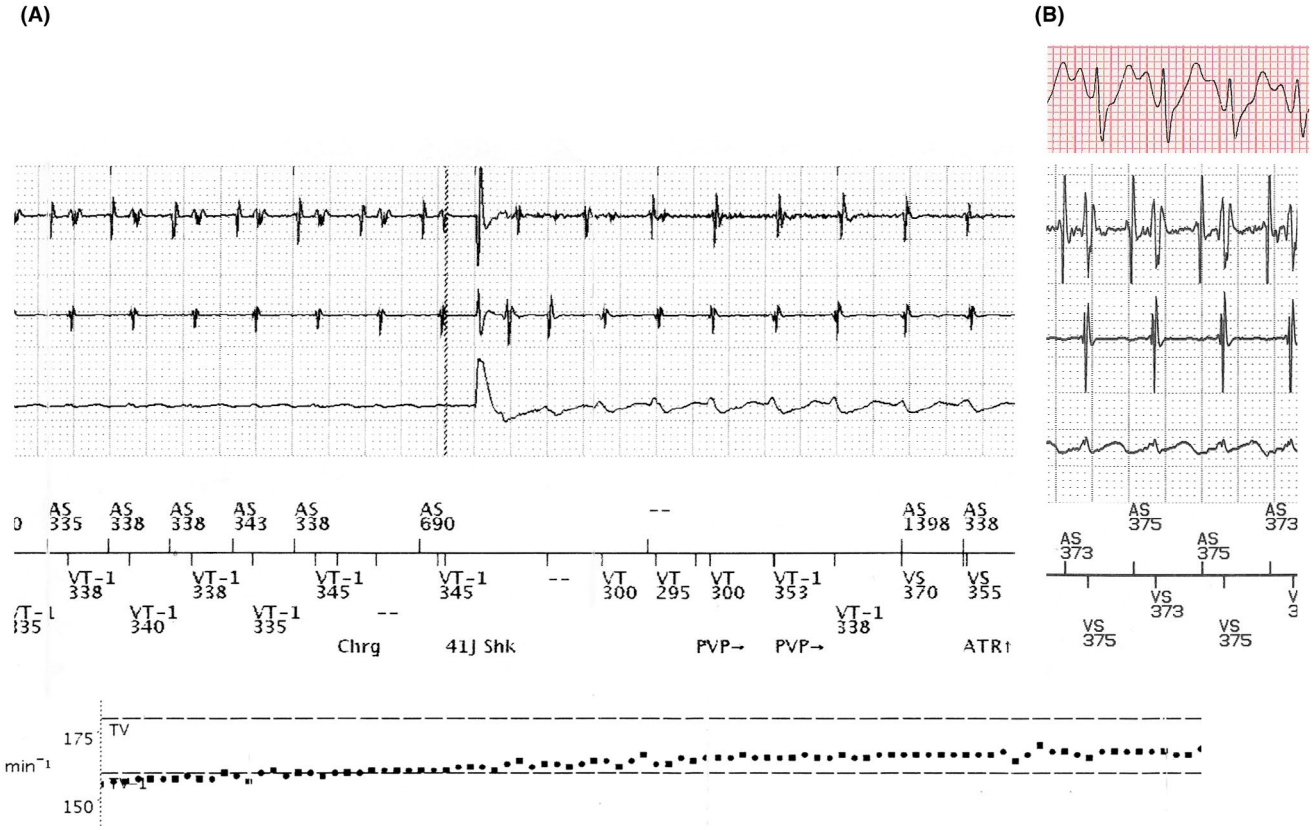

FIGURE 8 (A) Stored Electrogram of a 28-year-old female patient with congenital long QT syndrome and DDD cardioverter defibrillator, implanted for secondary prevention; she referred "shocks" during moderate physical effort. A and V electrograms, "shock" channel, markers and intervals. Sinus rate is 176 bpm, within the ventricular tachycardia diagnostic zone (VT-1) and receives an inappropriate 41 J shock (shk); the lower graph shows a non-paroxysmal onset and its increasing rate. (B) During the stress test under Bruce's protocol, a similar pattern was reproduced; this case exemplifies the potential conflict between the maximum rate reached with exercise and the ventricular tachycardia diagnostic zone programmed in the device

is necessary; and dynamic resynchronization algorithms that adjust these intervals automatically can also be useful.

In conclusion, pacemaker function in patients able to perform physical activity, should also be evaluated during exercise, since some abnormalities can arise that are not detected at rest; patients with tachyarrhythmia treatment devices, both atrial and ventricular, constitute the greatest challenge.

CONFLICT OF INTEREST

No conflicts declared.

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