Cardiac implantable devices during exercise: Normal function and troubleshooting

Oswaldo J. Gutiérrez MD

Clin Cardiol 2021;37:660–668.
www.journalofarrhythmia.org

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 some conflicts issues may arise that are not detectable during exercise, because some conflicts issues may arise that are not detectable during routine, at rest, telemetry.

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 pacing6-8 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

CLINICAL REVIEW

Cardiac implantable devices during exercise: Normal function and troubleshooting

Oswaldo J. Gutiérrez MD

Cardiology Department, Hospital Mexico, University of Costa Rica, San José, Costa Rica

Correspondence
Oswaldo J. Gutiérrez, Servicio de Cardiología, Sección 12, Hospital México, La Uruca, CP 10107 San José, Costa Rica.
Emails: oswcr@yahoo.com.ar; oswaldo.gutierrez@ucr.ac.cr

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 exercise, 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.
1.2 | 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. 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); 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), in these cases, errors can occur, such as a false diagnosis of a supraventricular tachyarrhythmias (Figure 3B), followed by inappropriate automatic mode switch function 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; or, as it has already been mentioned, a false
atrial tachyarrhythmia is misdiagnosed (Figure 4) or the automatic mode switch algorithm kicked in; or, in devices capable of treating atrial tachyarrhythmias, antitachycardia pacing is performed inappropriately.\textsuperscript{16,18} Attention should be paid to these intervals, especially when the MTR has been already adjusted 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.

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.
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. 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).

**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.

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; 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
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). 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; 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. 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)
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.

ORCID
Oswaldo J. Gutiérrez https://orcid.org/0000-0002-4821-2155

REFERENCES
1. Kusumoto FM, Schoenfeld MH, Barrett C, Edgerton JR, Ellenbogen KA, Gold MR, et al. 2018 ACC/AHA/HRS Guideline on the evaluation and management of patients with bradycardia and cardiac conduction delay: a report of the American college of cardiology/American heart association task force on clinical practice guidelines and the heart rhythm society. Circulation. 2019;140(8):e382–e482.
2. Ponikowski P, Voors AA, Anker SD, Bueno H, Cleland JGF, Coats AJS, et al. 2016 ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure: the Task Force for the diagnosis and treatment of acute and chronic heart failure of the European Society of Cardiology (ESC). Developed with the special contribution of the Heart Failure Association (HFA) of the ESC. Eur Heart J. 2016;37(27):2129-200.
3. Al-Khatib SM, Stevenson WG, Ackerman MJ, Bryant WJ, Callans DJ, Curtis AB, et al. 2017 AHA/ACC/HRS Guideline for Management of Patients With Ventricular Arrhythmias and the Prevention of Sudden Cardiac Death: a Report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines and the Heart Rhythm Society. J Am Coll Cardiol. 2018;72(14):e91–e220.
4. Dell’Orto S, Valli P, Greco EM. Sensors for rate responsive pacing. Indian Pacing Electrophysiol J. 2004;4(3):137–45.
5. Trohman RG, Huang HD, Larsen T, Krishnan K, Sharma PS. Sensors for rate-adaptive pacing: how they work, strengths, and limitations. J Cardiovasc Electrophysiol. 2020;31(11):3009–27.
6. Sweeney MO, Hellkamp AS, Ellenbogen KA, Greenspon AJ, Freedman RA, Lee KL, et al. MOde Selection Trial Investigators. Adverse effect of ventricular pacing on heart failure and atrial fibrillation among patients with normal baseline QRS duration in a clinical trial of pacemaker therapy for sinus node dysfunction. Circulation. 2003;107:2932–7.
7. Sweeney MO, Ellenbogen KA, Casavant D, Betzold R, Sheldon T, Tang F, et al. Multicenter, prospective, randomized safety and efficacy study of a new atrial-based managed ventricular pacing mode (MVP) in dual chamber ICDs. J Cardiovasc Electrophysiol. 2005;16:811–7.
8. Kolb C, Schmidt R, Dietl JU, Weyerbrock S, Morgenstern M, Fleckenstein M, et al. Reduction of right ventricular pacing with advanced atrioventricular search hysteresis: results of The PREVENT study. Pacing Clin. Electrophysiolo. 2011;34:975–83.
9. Payne GE, Skehan JD. Shuttle walking test: a new approach for evaluating patients with pacemakers. Heart. 1996;75(4):414–8.
10. Provenier F, Jordaens L. Evaluation of six minute walking test in patients with single chamber rate responsive pacemakers. Br Heart J. 1994;72(2):192–6.
11. Mulpuru SK, Madhavan M, McLeod CJ, Cha Y, Friedman PA. Cardiac Pacemakers: Function, Troubleshooting, and Management. J Am Coll Cardiol. 2017;69(2):189–210.
12. Mathony U, Schmidt H, Gröger C, Francis DP, Konzag I, Müller-Werdan U, et al. Optimal maximum tracking rate of dual-chamber pacemakers required by children and young adults for a maximal cardiorespiratory performance. Pacing Clin Electrophysiolo. 2005;28(5):378–83.
13. Barold SS. Wenckebach upper rate response of dual chamber pacemakers: a reappraisal and proposed new terminology. Pacing Clin. Electrophysiolo. 1995;18:244–52.
14. Stroobandt RX, Barold SS, Vandenbulcke FD, Willems RJ, Sinnaeve AF. A reappraisal of pacemaker timing cycles pertaining to automatic mode switching. J Interv Card Electrophysiolo. 2001;5(4):417–29.
15. Barold SS, Herweg B. Conventional and biventricular pacing in patients with first-degree atrioventricular block. Europace. 2020;14(10):1414–9.
16. Strik M, Socié P, Ploux S, Bordachar P. Unexpected and undesired side-effects of pacing algorithms during exercise. J Electrocardiol. 2018;51(6):1023–8.
17. de Voogt WG, van Hemel NM, van de Bos AA, Koistinen J, Fast JH. Verification of automatic mode switching for the detection of atrial fibrillation and atrial tachycardia with Holter recording. Europace. 2006;8(11):950–61.
18. Boriani G, Tukkie R, Manolis AS, Mont L, Pürerfellner H, Santini M, et al. Atrial antitachycardia pacing and managed ventricular pacing in bradycardia patients with paroxysmal or persistent atrial tachyarhythmias: the MINERVA randomized multicentre international trial. Eur Heart J. 2014;35(35):2352–62.
19. Varriale P, Chryssos BE. Atrial sensing performance of the single-lead VDD pacemaker during exercise. J Am Coll Cardiol. 1993;22(7):1854–7.
20. Strik M, Frontera A, Eschalier R, Defaye P, Mondoly P, Ritter P, et al. Accuracy of the pacemaker-mediated tachycardia algorithm in Boston Scientific devices. J Electrocardiol. 2016;49(4):522–9.
21. Smith M, Lavu M, Kazimuddin M. Completely blocked: an asymptomatic 20-year-old. Poster ACC.19. J Am Coll Cardiol. 2019;73(9):2455.
22. Kulkarni N, Link MS. Causes and Prevention of Inappropriate Implantable Cardioverter-Defibrillator Shocks. Card Electrophysiolo Clin. 2018;10(1):67–74.
23. Tzeis S, Andrikopoulos G, Kolb C, Vardas PE. Tools and strategies for the reduction of inappropriate implantable cardioverter defibrillator shocks. Europace. 2008;10(11):1256–65.
24. Heidbuchel H, Carré F. Exercise and competitive sports in patients with an implantable cardioverter-defibrillator. Eur Heart J. 2014;35(44):3097–102.
25. Atwater BD, Emerek K, Loring Z, Polciwiatek C, Jackson KP, Friedman DJ. Frequency and causes of QRS prolongation during exercise electrocardiogram testing in biventricular paced patients with heart failure. HeartRhythm Case Rep. 2020;6(6):308–12.

How to cite this article: Gutiérrez OJ. Cardiac implantable devices during exercise: Normal function and troubleshooting. J Arrhythmia. 2021;37:660–668. https://doi.org/10.1002/joa3.12529