Iatrogenic pacemaker-induced ventricular arrhythmia: a case report

Vivetha Pooranachandran 1,2*, Tim Hodson3, Will Nicolson 1,3, and Ghulam Andre Ng 1,2,3

1Department of Cardiovascular Sciences, University of Leicester, Leicester, UK; 2NIHR Leicester Biomedical Research Centre, Leicester, UK; and 3Department of Cardiology, University Hospitals of Leicester NHS Trust, Leicester, UK

Received 4 August 2021; first decision 31 August 2021; accepted 29 April 2022; online publish-ahead-of-print 3 May 2022

Background
Minimizing right ventricular (RV) pacing to reduce the progression of heart failure is an established practice. Proprietary algorithms to reduce unnecessary RV pacing have been incorporated into both simple and complex cardiac pacemaker devices, for reducing the possibility of heart failure and arrhythmias.

Case summary
We present a case of a 43-year-old male implanted with a dual-chamber primary prevention implantable cardioverter-defibrillator (AUTOGEN EL, Boston Scientific) for sudden cardiac death. At the time of implant, the patient had hypertrophic cardiomyopathy with mild left ventricular (LV) systolic impairment, and sinus rhythm with intact atrioventricular (AV) conduction. The patient developed progression of his disease with symptoms (dyspnoea) and LV impairment. This led to a decision to activate the minimal RV pacing algorithm (RYTHMIQ™). A deterioration in AV conduction caused intrinsic ventricular beats to fall in the atrial blanking period, and subsequent VVI backup pacing resulted in R on T pacing. This induced ventricular arrhythmia. RYTHMIQ™ was subsequently deactivated, and the patient has had no further device-induced arrhythmias.

Discussion
Numerous studies have demonstrated the adverse effect of RV pacing on LV function. Minimizing RV pacing is, therefore, encouraged in individuals with intact AV conduction. However, underlying conduction abnormalities must be assessed prior to activating algorithms designed to minimize RV pacing. This case demonstrates the importance of careful intracardiac electrogram interpretation and individual case-based device programming, to avoid device-induced complications.

Keywords
Case report • Implantable cardioverter-defibrillator • Ventricular arrhythmia • RYTHMIQ

ESC Curriculum
5.6 Ventricular arrhythmia • 5.10 Implantable cardioverter-defibrillators

Learning points
• RYTHMIQ™ should be used with caution in patients with known intermittent atrioventricular (AV) dissociation.
• In patients with no ventricular pacing indication, a Wenckebach pacing test or pacing at sensor indicated rate may be performed to assess AV conduction abnormalities.
Introduction

Widespread research has demonstrated that although dual-chamber pacing restores atrioventricular (AV) synchrony, right ventricular (RV) pacing-induced mechanical dyssynchrony may lead to progressive left ventricular (LV) dysfunction, promoting heart failure. This encouraged the design of programmable device algorithms to reduce unnecessary RV pacing. Here, we present an iatrogenic case of device-induced ventricular arrhythmia.

Case presentation

A 43-year-old male was implanted with a dual-chamber implantable cardioverter-defibrillator (ICD) for primary prevention. The patient presented with dyspnoea and had a family history of sudden cardiac death. No other past medical history. Implanted with primary prevention implantable cardioverter-defibrillator (ICD).

Timeline

| Date       | Events                                                                 |
|------------|------------------------------------------------------------------------|
| 2015       | Elective ICD generator replacement                                      |
| 2016       | Presented with worsening dyspnoea. Echocardiogram demonstrated moderate LV systolic impairment. RYTHMIQ™ was programmed on. |
| 17 May 2017 | Device check demonstrated normal function and parameters               |
| 18 May 2017 | Device-induced ventricular arrhythmia. Physical examination demonstrated no abnormalities. |

Discussion

RYTHMIQ™ and AV Search+
RYTHMIQ™ is a Boston Scientific feature designed to encourage intrinsic conduction. It is a programmable feature and is nominally set

Table 1  Echocardiogram parameters of hypertrophic cardiomyopathy²

| Left ventricular dimensions and volumes | Initial echocardiogram | Echocardiogram in 2016 | Normal range (male) |
|----------------------------------------|------------------------|------------------------|---------------------|
| IVS diastole (mm)                      | 17                     | 18                     | 6–12                |
| LVPW diastole (mm)                     | 9.5                    | 8.8                    | 6–12                |
| LVID diastole (mm)                     | 40                     | 42                     | 37–56               |
| LVEDV indexed ml/m²                    | 71.4                   | 78.1                   | 30–79               |
| LVEF %                                 | Mildly impaired (visually) | Moderately impaired (visually) | ≥55%                |

Relative wall thickness in left ventricular hypertrophy

|               | Eccentric | Concentric |
|---------------|-----------|------------|
| 0.66          | ≤0.42     | >0.42      |

IVS, interventricular septum; LVPW, left ventricular posterior wall; LVID, left ventricular internal diameter; LVEDV, left ventricular end-diastolic volume; LVEF, left ventricular ejection fraction.
to off. RYTHMIQ™ operates in AAI(R) pacing mode with asynchronous VVI backup pacing during normal AV conduction. A loss of AV synchrony will automatically switch the device to DDD(R) mode, and a return in normal AV conduction will switch back to AAI mode with VVI backup.

- AAI(R) pacing is delivered at the LRL and/or SIR.
- VVI backup pacing is delivered at a rate of 15 ppm below the programmed LRL, i.e. LRL programmed at 60 ppm, VVI backup will be

---

**Figure 1** Device measurements taken 1 day prior to shock.

**Figure 2** Example of ventricular arrhythmia in the context of RYTHMIQ. (A) Device functioning in AAIR mode at sensor indicated rate and (B) back up VVI pacing followed by R on T pacing-induced ventricular arrhythmia.
**Table 2  Device algorithms designed to reduce ventricular pacing**

**Boston Scientific**

RYTHMION™
- Atrial based pacing with asynchronous VVI backup pacing (lower rate limit minus 15 ppm). Switch to DDD(R) mode occurs if:
  1. Three slow ventricular beats are detected in a window of 11 beats
  2. If V-V intervals are longer than A-A + 150 ms
- Intrinsic ativoventricular (AV) conduction is assessed by increasing AV delay periodically for up to eight consecutive paced or sensed cardiac cycles. If present, the longer AV Search+ AV delay will remain active. AV delay will revert to the programmed setting:
  1. When no intrinsic ventricular activity is detected during the periodic search cycle or
  2. When two ventricular paced (VP) events are detected within a 10-cycle moving window

**Medtronic**

Managed ventricular pacing (MVP)
- Atrial based pacing [AAI(R)] with switch to DDD(R) mode if:
  1. 2 out of 4 intrinsic ventricular activity is absent
  2. Average PR interval over four consecutive cycles exceeds the programmed PR value (by default the long PR function of the algorithm is switched OFF)
- Intrinsic AV conduction is assessed in the 16 most recent cycles and adjusts the sensed and paced AV delays to promote intrinsic activation of the ventricles. Based on the AV conduction time, the AV delays are either lengthened by 62 ms or shortened by 8 ms for the next 16 pacing cycles.

**St. Jude Medical™**

Ventricular intrinsic preference (VIP)
- Intrinsic AV conduction is assessed using AV hysteresis (up to 450 ms) at regular intervals (AV extension, search intervals and number of cycles are programmable). If intrinsic conduction is absent for a programmed number of cycles (i.e. ventricular pacing at the end of extended AV delay), AV delay will shorten to the programmed value until the next search interval.

**Sorin**

SafeR
- Atrial based pacing AAI(R) with switch to DDD(R) mode if:
  1. PR interval exceeds the ‘long PR interval’ (programmable) for six consecutive beats (AV block I criteria)
  2. 3/12 non-conducted atrial events (AV block II criteria)
  3. Two consecutive non-conducted atrial events (AV block III criteria)
  4. Ventricular pauses of 2–4 s (programmable)

**Biotronik**

AV hysteresis
- Intrinsic AV conduction is assessed using AV hysteresis (AV delay extended to 450 ms) for eight cycles. Mode switch to ADI(R) if 6/8 beats are ventricular sensed events. VP suppression
- Mode switch to DDD(R) if:
  1. PR interval >450 ms in two cycles
  2. No intrinsic ventricular activity ≥2 s
  3. Two consecutive non-conducted atrial events
  4. Three non-conducted atrial events in a rolling window of eight events
45 ppm. The backup VVI pacing rate is limited to a minimum of 30 ppm and maximum of 60 ppm.

- The device switches from AAI(R) to DDD(R) mode when three slow ventricular beats are detected in a window of 11 beats. A slow ventricular event is defined as: (i) ventricular paced beat, (ii) V-V interval greater than A-A interval + 150 ms.

In DDD(R) mode, the device uses AV Search + algorithm to assess the return of normal AV conduction.

AV Search +:

- AV Search + promotes intrinsic conduction by periodically extending the AV delay. This occurs every 32–1024 ventricular cycles with AV Search delay of 30–400 ms (both programmable search parameters).
- If <2 out of the last 10 ventricular events are paced or sustained conduction is detected for >25 beats, the device will switch to AAI(R) mode with VVI backup.

Note: If AV Search + is programmed off, switch from AAI(R) with VVI backup to DDD(R) mode will only occur once, until the device is reprogrammed.

Atrioventricular conduction disease is a common indication for device implantation. As per the European Society of Cardiology guideline for cardiac pacing and cardiac resynchronization therapy, AV synchronous pacing is recommended in advanced AV block, however, ventricular pacing for prolonged first-degree AV delay is an ongoing debate.4

A prolonged AV delay impairs LV filling, and reducing ventricular pacing may not be desirable in view of the haemodynamic response.4 On the contrary, several studies have demonstrated RV pacing to be associated with an increased risk of death and heart failure hospitalization, ventricular dyssynchrony and propensity to atrial fibrillation, questioning the optimal device setting in patients with prolonged AV delay.5,6

To provide an appropriate level of AV synchronous pacing, many pacemaker manufacturers (St Jude Medical/Abbott, Boston Scientific, Sorin, Biotronik, and Medtronic) have incorporated a minimal RV pacing feature into both simple and complex devices. With the exception of RYTHMIQ™, other algorithms are designed to provide a backup synchronous ventricular response to A-A intervals that are missing ventricular sensed events (number of allowed non-conducted atrial events and programmable AV interval vary between manufacturers). Thus, reducing the likelihood of R on T pacing (Table 2).

The RYTHMIQ™ feature, which is present in simple pacemaker devices, may have proven fatal for our patient if he did not have a defibrillator. Similar incidences with RYTHMIQ™ were previously reported to be proarrhythmic, though these were as a result of short-long-short coupling intervals.7,8

Our case highlights the importance of regular follow-up and individual case-based device programming to prevent potential device issues. RYTHMIQ™ stores a 20 s electrogram data in the Arrhythmia logbook which must be carefully interpreted to distinguish between pathological and algorithm-induced arrhythmias. In addition, a simple Wenckebach pacing test or pacing at SIR may be performed to assess AV conduction abnormalities before activating RYTHMIQ™. A Wenckebach test involves pacing a patient’s heart at a faster rate than their AV node can handle (most often at the programmed max sensor/track rate). In some cases, this can result in 1st degree AV block or Wenckebach, which can be viewed on the paced electrocardiogram. This will help determine appropriate settings to avoid possible complications.7 Patients with heart failure who require ventricular pacing due to AV conduction disease may additionally benefit from cardiac resynchronization therapy (Table 3).10 This will help restore ventricular synchrony and may improve LV systolic function.11 Our patient did not meet the criteria for a cardiac resynchronization therapy (QRS duration; 90 ms, mild LV function), however, this patient may benefit from the emerging conduction system pacing, which hopes to preserve or normalize biventricular activation with pacing.12 In light of this arrhythmia episode, RYTHMIQ™ was deactivated in the patient’s ICD. A subsequent 3 year follow-up demonstrated no further device-induced arrhythmias.

RYTHMIQ™ has been designed to promote intrinsic conduction with the safety of backup pacing. We highlight the need for careful individual assessment prior to programming this feature on, to avoid pacing-induced arrhythmias.

| Table 3 Cardiac defibrillator options for patients with left ventricular dysfunction and a left ventricular ejection fraction of ≤35% |
|---|---|---|---|---|
| QRS duration | New York Heart Association |
| <120 ms | ICD if at high risk of SCD | ICD and CRT not clinically indicated |
| 120–149 ms without left bundle branch block | ICD | CRT-P |
| 120–149 ms with left bundle branch block | CRT-D | CRT-P |
| ≥150 ms with or without left bundle branch block | CRT-D | CRT-P |

Adapted from National Institute for Health and Care Excellence [TA314].10 ICD, implantable cardioverter-defibrillator; CRT-P, cardiac resynchronisation therapy-pacemaker; CRT-D, cardiac resynchronization therapy-defibrillator.

Lead author biography

Vivetha is a PhD candidate at the University of Leicester. Research interests include Ventricular Arrhythmia and Sudden Cardiac Death.

Supplementary material

Supplementary material is available at European Heart Journal—Case Reports online.

Slide sets: A fully edited slide set detailing this case and suitable for local presentation is available online as Supplementary data.
Consent: The authors confirm that written consent for the submission and publication of this case, including images, has been obtained from the patient in line with COPE guidance.

Conflict of interest: None declared.

Funding: V.P. is supported by the NIHR Leicester Biomedical Research Centre with a Research Fellowship. G.A.N. is supported by a British Heart Foundation Programme Grant (RG/17/3/32774). W.N. and G.A.N. are supported by a Medical Research Council Biomedical Catalyst Developmental Pathway Funding Scheme (MR/S037306/1).

References
1. O’Keefe JH Jr, Abuissa H, Jones PG, Thompson RC, Bateman TM, McGhie AI, Ramza BM, Steinhauser DM. Effect of chronic right ventricular apical pacing on left ventricular function. Am J Cardiol 2005;95:771–773.
2. Harkness A, Ring L, Augustine DX, Oxborough D, Robinson S, Sharma V. Normal reference intervals for cardiac dimensions and function for use in echocardiographic practice: a guideline from the British Society of Echocardiography. Echo Res Pract 2020;7:G1–G18.
3. Authors/Task Force Members, Brignole M, Auricchio A, Baron-Esquivias G, Bordachar P, Boriani G, Breithardt O-A, Cleland J, Deharo J-C, Delgado V, Elliott PM, Gorenek B, Israel CW, Leclercq C, Linde C, Mont L, Padeletti L, Sutton R, Vardas PE. 2013 ESC Guidelines on cardiac pacing and cardiac resynchronization therapy: the Task Force on cardiac pacing and cardiac resynchronization therapy of the European Society of Cardiology (ESC). Developed in collaboration with the European Heart Rhythm Association (EHRA). Eur Heart J 2013;34:2281–2329.
4. Keene D, Arnold A, Shun-Shin MJ, Howard JP, Sohaib SA, Moore P, Tanner M, Quereshi N, Muthumala A, Chandrasekaran B, Foley P, Leyva F, Adhya S, Falaschetti E, Tsang H, Vijayaraman P, Cleland JGF, Stegemann B, Francis DP, Whinnett ZI. Rationale and design of the randomized multicentre His Optimized Pacing Evaluated for Heart Failure (HOPE-HF) trial. ESC Heart Fail 2018;5:965–976.
5. Wilkoff BL, Cook JR, Epstein AE, Greene HL, Halstrom AP, Haia H, Kutalek SP, Sharma A. Dual-chamber pacing or ventricular backup pacing in patients with an implantable defibrillator: the Dual Chamber and VVI Implantable Defibrillator (DAVID) Trial. JAMA 2002;288:3115–3123.
6. Sweeney MO, Bank AJ, Nash E, Koullck M, Zeng QC, Hettrick D, Sheldon T, Lamas GA. Minimizing ventricular pacing to reduce atrial fibrillation in sinus-node disease. N Engl J Med 2007;357:1000–1008.
7. Monkhouse C, Dillon T, Chow AW, Behar JM. AV hysteresis causing initiation of recurrent atrial arrhythmias. Pacing Clin Electrophysiol 2018;41:1552–1554.
8. Nguyen T, Steira J, Casado-Arroyo R. Increased risk of ventricular fibrillation associated with RYTHMIQ™: lessons learned. J Interv Card Electrophysiol 2017;48:111–112.
9. Adachi M, Igawa O, Yano A, Miske J, Inoue Y, Ogura K, Kato M, Itsuaka K, Hisatome I. Long-term reliability of AAi mode pacing in patients with sinus node dysfunction and low Wenckebach block rate. Europace 2008;10:134–137.
10. National Institute of Health and Care Excellence. NICE technology appraisal [TA 314]: Implantable cardioverter defibrillators and cardiac resynchronisation therapy for arrhythmias and heart failure (review of TA95 and TA120). 2014.
11. St John Sutton MG, Plappert T, Abraham WT, Smith AL, DeLurgio DB, Leon AR, Loh E, Kocovic DZ, Fisher WG, Elestad M, Messenger J, Kruger K, Hilipsch KE, Hill MRS. Effect of cardiac resynchronization therapy on left ventricular size and function in chronic heart failure. Circulation 2003;107:1985–1990.
12. Sharma PS, Dandamudi G, Herweg B, Wilson D, Singh R, Naperkowski A, Koneru JN, Ellenbogen KA, Vijayaraman P. Permanent His-bundle pacing as an alternative to biventricular pacing for cardiac resynchronization therapy: a multicenter experience. Heart Rhythm 2018;15:413–420.

V. Pooranachandran et al.