

Proarrhythmic effects of dynamic atrioventricular delay programming in a patient with cardiac resynchronization therapy and activity-induced atrioventricular node dysfunction



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Introduction

Biventricular pacing has been shown to improve cardiac function, reduce heart failure hospitalizations, and reduce the risk of atrial and ventricular arrhythmias. Attempts at routine optimization of cardiac resynchronization through echocardiography or electrocardiography have failed to consistently improve clinical outcomes perhaps owing to the dynamic changes in atrioventricular (AV) node function and conduction velocity outside of the optimization period.^{1–4} On the basis of these trials, multiple algorithms have been created to allow dynamic adjustments to the AV delays based on intrinsic AV conduction timing, which facilitates fusion of left ventricular (LV) pacing to intrinsic right ventricular (RV) conduction in hopes of improving clinical outcomes. Algorithmic assessment of native AV conduction timing may require lengthening and then shortening of the R-R intervals to allow timing-appropriate LV pacing. While optimization of AV synchrony and LV pacing may improve heart failure–related symptoms, the dynamic changes in the R-R intervals created by these algorithms may precipitate ventricular tachyarrhythmias.

Case report

The patient is a 66-year-old man who initially presented 3 years prior with syncope and ventricular tachycardia (VT) (Figure 1). A transthoracic echocardiogram at the time of

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KEY TEACHING POINTS

- Pacing algorithms that automatically adjust the intervals between paced beats may be proarrhythmic.
- Exercise-mediated atrioventricular block or exercise-mediated prolongation of the PR interval needs to be considered prior to use of the SyncAV cardiac resynchronization therapy (CRT) algorithm.
- If ventricular tachycardia is induced by the SyncAV CRT algorithm, there are multiple possible programming strategies that can be considered to prevent recurrence.

presentation identified a new cardiomyopathy with an LV ejection fraction of 25%. A coronary angiogram did not identify obstructive coronary artery disease. Cardiac magnetic resonance imaging identified scar along the basal septum extending along the free wall of the RV with a dilated RV and severely reduced RV systolic function. Shortly after presentation he developed intermittent complete heart block. A positron emission tomography scan was performed and identified a small area of enhancement along the mid septum without any areas of extracardiac enhancement. An electroanatomic mapping–guided biopsy was performed but was negative for sarcoidosis or giant cell myocarditis and a cardiac resynchronization therapy defibrillator (CRT-D) system (Quadra Assura 3369–40Q, St Jude Medical, St Paul, MN) was placed. Following optimization of his heart failure medications he had symptomatic improvement with increased energy and less shortness of breath, but his LV ejection fraction remained severely reduced. Despite use of carvedilol and amiodarone, the patient had recurrent VT resulting in

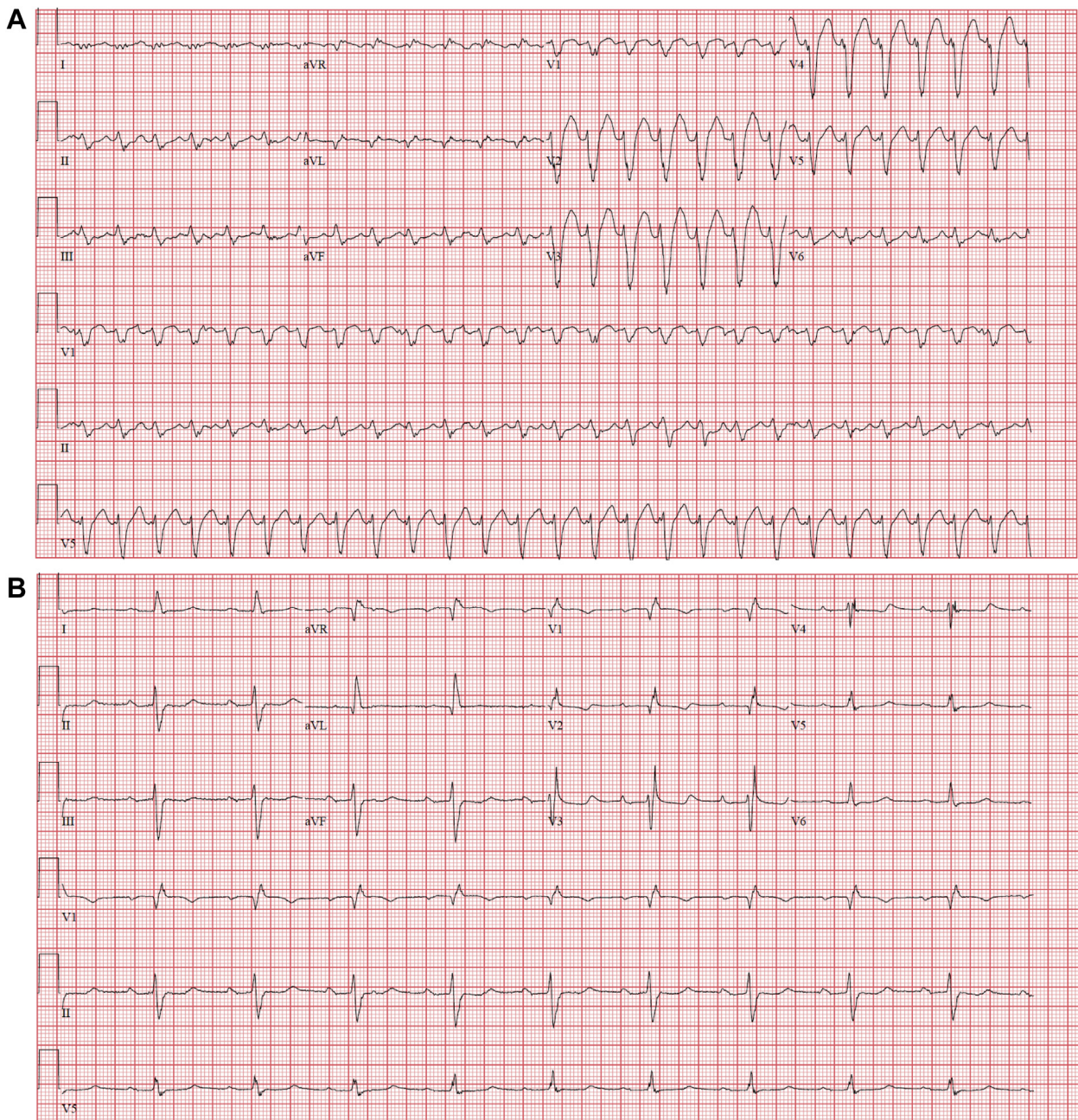


Figure 1 A: Presenting electrocardiogram (ECG) with ventricular tachycardia. B: ECG following ventricular tachycardia termination showing sinus rhythm with first-degree atrioventricular block and left axis deviation with nonspecific intraventricular conduction delay.

therapies from his device and underwent an endocardial and epicardial ablation, which resulted in adequate control of his VT.

After reaching Elective Replacement Interval, he underwent generator change and received an Abbott Gallant HF CRT-D generator (Abbott, Abbott Park, IL). The device was programmed DDDR with a lower rate limit of 60 beats per minute with a maximum sensing and tracking rate of 120 beats per minute. Owing to the presence of intact AV node conduction, SyncAV™ Plus CRT was turned on with paced and sensed AV delays of 160 ms and 110 ms, respectively. The QRS width of biventricular paced complexes

prior to SyncAV was 126 ms. Following SyncAV activation, the QRS width decreased to 114 ms (Figure 2). Note that SyncAV Plus CRT is not intended for patients who exhibit complete AV block or PR intervals greater than 300 ms.

Three days after generator change, the patient contacted our clinic to report symptoms of lightheadedness, nausea, and loss of energy reminiscent of prior VT episodes. These episodes were reproducible when walking short distances and occurred multiple times per walk. The episodes did not occur prior to generator replacement.

On device interrogation and review of electrograms, all leads had stable function. However, there were frequent

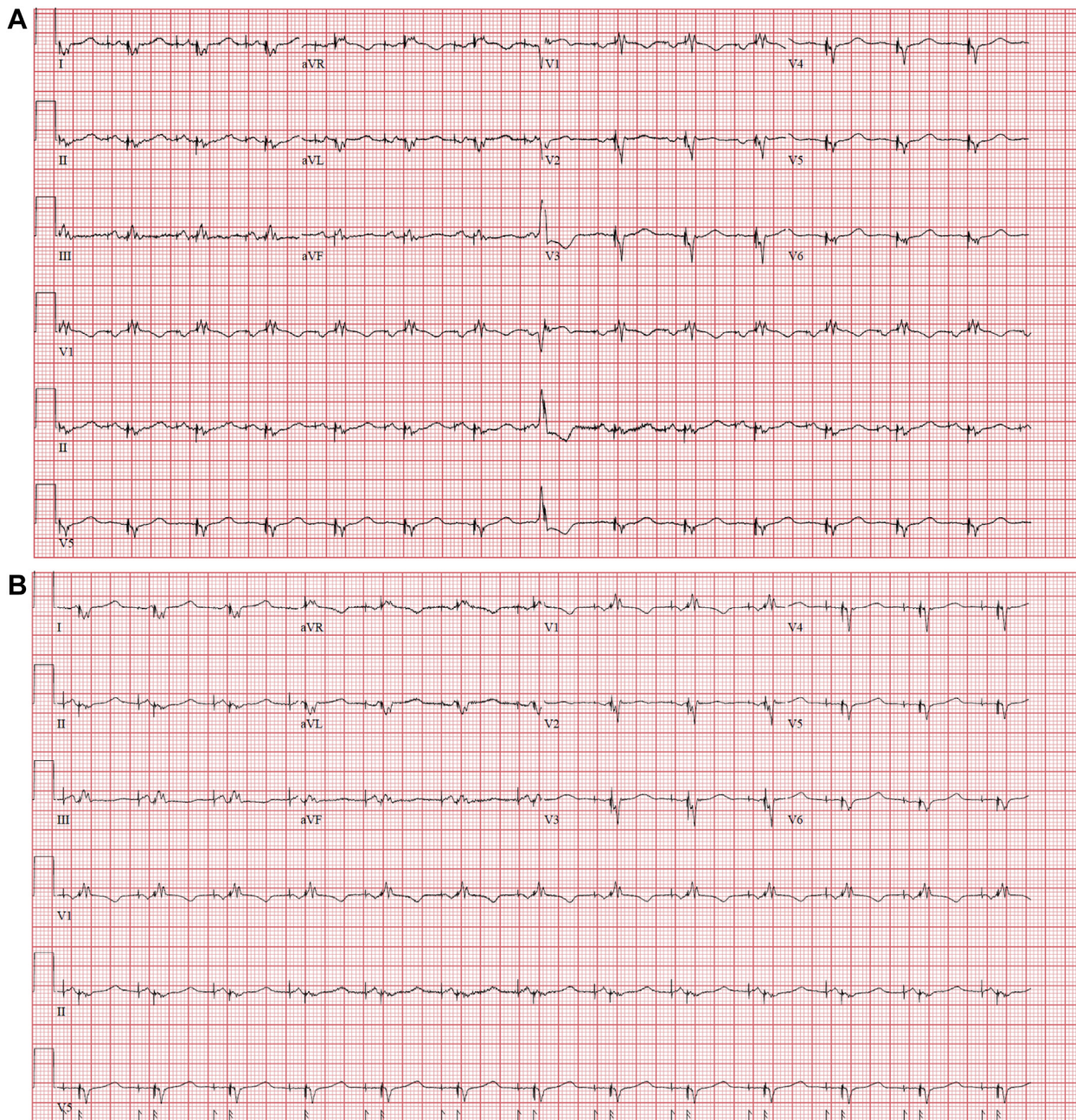


Figure 2 A: Electrocardiogram (ECG) following placement of the initial cardiac resynchronization therapy defibrillator system without SyncAV. B: ECG after generator change with SyncAV turned on. With SyncAV turned on, the QRS duration shortened from 126 ms to 114 ms.

episodes of nonsustained monomorphic and polymorphic VT that corresponded to the timing of his symptoms. All of the episodes occurred after the SyncAV algorithm initiated to calculate the AV conduction time by first lengthening the AV delay and then shortening the AV delay after AV conduction was not seen (Figure 3). While the patient had intact AV conduction at the time of generator replacement, either complete heart block occurred with increased physical activity or the PR interval lengthened beyond the programmed AV delay, resulting in failure to detect AV conduction. SyncAV Plus CRT was therefore disabled. On subsequent clinic en-

counters, VT was no longer observed and the patient reported complete resolution of his symptoms.

Discussion

In the present case, lengthening of the AV delay for 5 beats to facilitate detection of AV node conduction, followed by abrupt shortening of the AV delay after failure to detect AV conduction, was capable of repeatedly inducing symptomatic nonsustained VT. There are numerous reports of pacemaker algorithms causing VT,

1: A Sense Amp AutoGain (8.8 mm/mV)
 2: V Sense Amp AutoGain (3.5 mm/mV)
 3: Discrimination AutoGain (9.0 mm/mV)

4: Markers

Sweep Speed: 25 mm/s

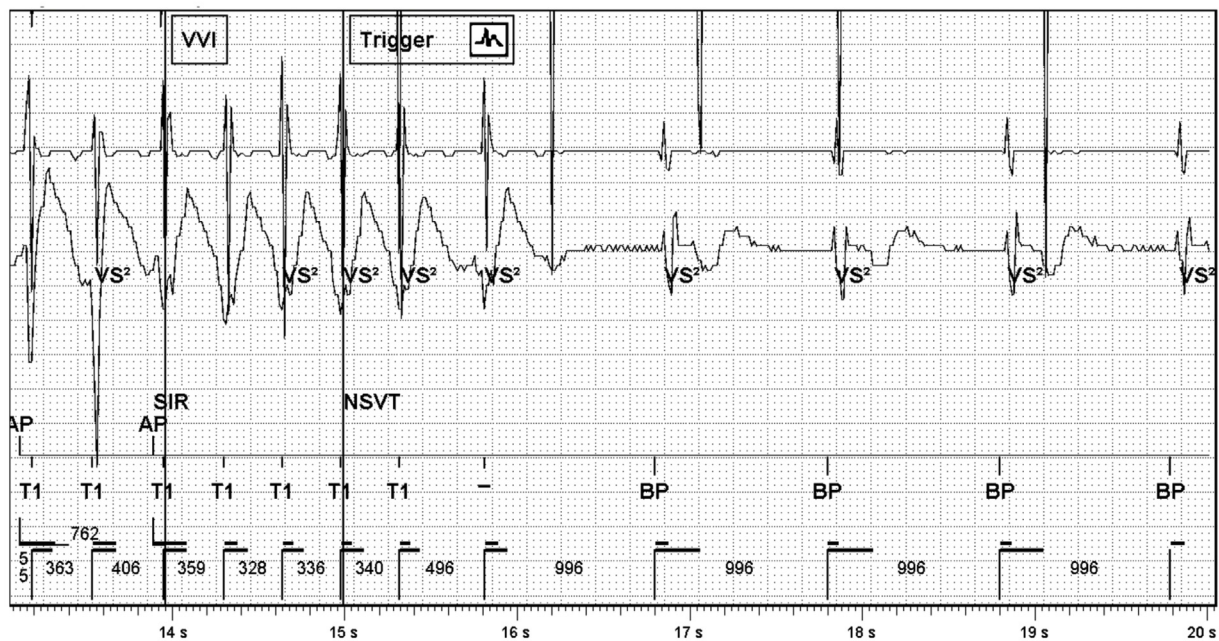
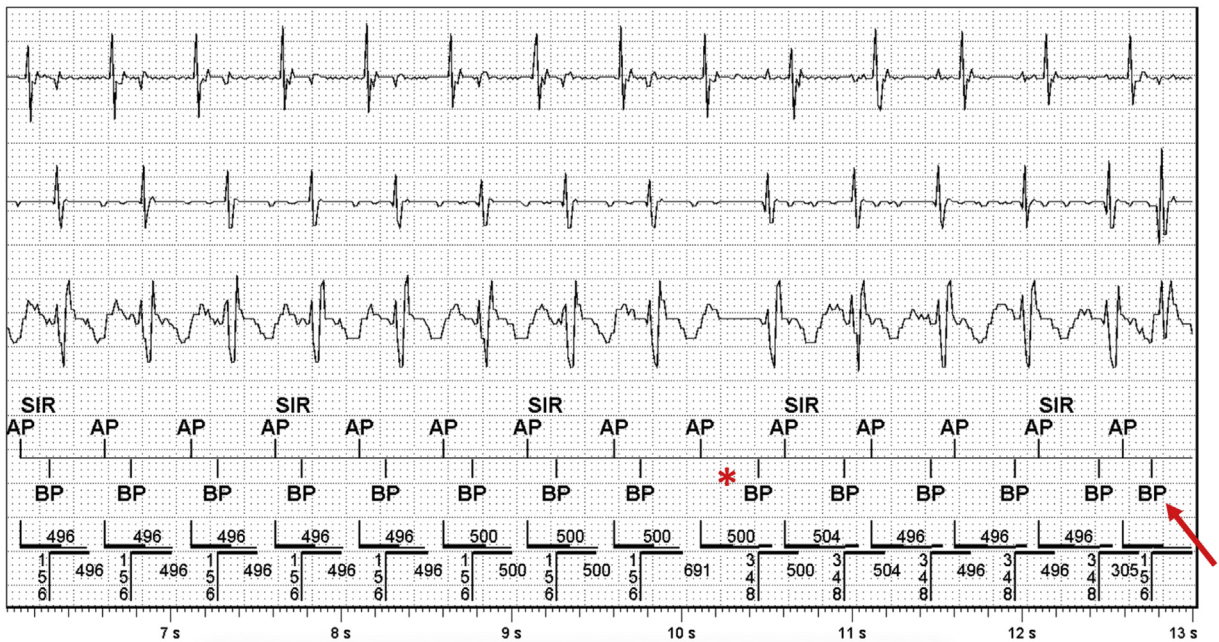


Figure 3 Electrograms from a representative episode of ventricular tachycardia triggered by the SyncAV Plus cardiac resynchronization therapy (CRT) algorithm. During each episode, the patient was active, as indicated by SIR (activity Sensor-Indicated Rate) with atrial-paced and biventricular pacing with a programmed atrioventricular (AV) delay of 160 ms. The SyncAV Plus CRT algorithm results in lengthening of the AV delay (denoted *) to 350 ms. After 5 beats with failure to detect native AV conduction (during which time the R-R interval is at the maximal sensor rate around 500 ms), the AV delay is shortened back to 156 ms (arrow), resulting in shortening the R-R interval to 305 ms. Following the shortened paced R-R interval (akin to a delivered single ventricular extrastimulus), nonsustained ventricular tachycardia (VT) is induced. Following spontaneous VT termination, biventricular paced rate decreases to 1000 ms to facilitate redetection of VT. AP = atrial pace; BP = biventricular pace; NSVT = nonsustained ventricular tachycardia; SIR = sensor indicated rate; T1 = ventricular tachycardia zone 1.

specifically Managed Ventricular Pacing (Medtronic, Minneapolis, MN).⁵⁻⁸ This is the first reported case of VT induced by an adaptive AV delay programming algorithm that we are aware of.

Automated algorithms time ventricular pacing to allow utilization of native right bundle conduction and facilitate improvement in ventricular activation. However, given the dynamic changes to AV node conduction velocity,

biventricular pacemakers need to regularly reassess the appropriate timing of LV pacing impulse delivery. In order to calculate this interval, the SyncAV Plus CRT algorithm lengthens the AV delay for up to 5 beats in order to calculate the native AV conduction time. If native conduction is detected (ie, ventricular sensed events), the AV delays are set to the measured AV conduction interval shortened by a programmable percentage (nominally 15%). If native conduction is not sufficiently detected, the AV delays are set to the previously programmed AV delays (nominally 160 ms), and native AV conduction is reassessed every 256 beats.⁹ The 256-beat search interval doubles with every successive absence of native AV conduction to minimize the use of longer AV delays, but reverts to 256 beats when AV conduction is redetected. However, upon failure to detect native AV conduction, abrupt shortening of the paced AV delay results in a relatively early ventricular beat (similar to a ventricular extrastimulus performed during an electrophysiology study), which, in this particular patient, repeatedly triggered VT.

Following these episodes, we opted to turn off SyncAV Plus CRT, which resulted in complete elimination of the episodes. However, several alternative programming solutions exist with SyncAV still enabled. First, the programmed AV delay, which SyncAV reverts to when AV conduction block is identified, could be lengthened. This would curb the decrease in R-R intervals when biventricular pacing resumes. Second, the extended AV delay temporarily applied during AV search could be shortened, which would have the same effect. Third, the number of beats during the AV search window (ie, 5) could be reduced to limit adaptation to a prolonged AV delay. However, only the first option is readily available for reprogramming.

Previous studies have demonstrated that epicardial pacing delivered by CRT devices can be proarrhythmic. The mechanism of proarrhythmia appears to be multifactorial, but may be related to increased dispersion of ventricular repolarization during epicardial pacing, as well as pacing within or near a critical isthmus in myocardial scar.^{10–12} The increased myocardial dispersion from epicardial pacing and the ventricular extrastimulus from the SyncAV CRT algorithm may have both contributed to the development of ventricular arrhythmias seen in this case.

A multicenter study found that SyncAV CRT and use of patient-specific offsets can provide a greater reduction in QRS duration and electrical synchrony compared to optimized traditional biventricular pacemaker programming.¹³ A retrospective study reviewing data from Abbott's patient device tracking database and remote monitoring network and the Medicare fee-for-service repository suggests that use of SyncAV CRT has contributed to decreases in heart failure hospitalization costs.¹⁴ While such studies highlight

advantages offered by SyncAV CRT, caution is warranted in using any algorithm that creates abrupt shortening of a paced R-R interval owing to the risk of unintended induction of ventricular tachyarrhythmias, which may result from normal algorithm functioning.

Conclusion

This case illustrates the risk of inducing VT during normal function of the SyncAV Plus CRT algorithm in a patient with activity-induced impaired AV node function. After failure to detect intact AV conduction, abrupt shortening of the AV delay resulted in a relatively early ventricular paced beat, akin to the delivery of a ventricular extrastimulus during an electrophysiology study, repeatedly triggering symptomatic nonsustained VT. If observed, there are multiple possible programming strategies to consider to prevent recurrence of this proarrhythmic situation.

References

1. Brabham WW, Gold MR. The role of AV and VV optimization for CRT. *J Arrhythmia* 2013;29:153–161.
2. Ellenbogen KA, Gold MR, Meyer TE, et al. Primary results from the SmartDelay determined AV optimization: a comparison to other AV delay methods used in cardiac resynchronization therapy (SMART-AV) trial: a randomized trial comparing empirical, echocardiography-guided, and algorithmic atrioventricular delay programming in cardiac resynchronization therapy. *Circulation* 2010;122:2660–2668.
3. Sawhney NS, Waggoner AD, Garhwal S, Chawla MK, Osborn J, Faddis MN. Randomized prospective trial of atrioventricular delay programming for cardiac resynchronization therapy. *Heart Rhythm* 2004;1:562–567.
4. Vidal B, Sitges M, Marigliano A, et al. Optimizing the programming of cardiac resynchronization therapy devices in patients with heart failure and left bundle branch block. *Am J Cardiol* 2007;100:1002–1006.
5. van Mechelen R, Schoonderwoerd R. Risk of managed ventricular pacing in a patient with heart block. *Heart Rhythm* 2006;3:1384–1385.
6. Mansour F, Talajic M, Thibault B, Khairy P. Pacemaker troubleshooting: when MVP is not the most valuable parameter. *Heart Rhythm* 2006;3:612–614.
7. Sweeney MO, Ruetz LL, Belk P, Mullen TJ, Johnson JW, Sheldon T. Bradycardia pacing-induced short-long-short sequences at the onset of ventricular tachyarrhythmias: a possible mechanism of proarrhythmia? *J Am Coll Cardiol* 2007;50:614–622.
8. Mansour F, Khairy P. Electrical storm due to managed ventricular pacing. *Heart Rhythm* 2012;9:842–843.
9. Varma N, O'Donnell D, Bassiouny M, et al. Programming cardiac resynchronization therapy for electrical synchrony: reaching beyond left bundle branch block and left ventricular activation delay. *J Am Heart Assoc* 2018;7:e1–e12.
10. Fish JM, Di Diego JM, Nesterenko V, Antzelevitch C. Epicardial activation of left ventricular wall prolongs QT interval and transmural dispersion of repolarization: implications for biventricular pacing. *Circulation* 2004;109:2136–2142.
11. Medina-Ravell VA, Lankipalli RS, Yan GX, et al. Effect of epicardial or biventricular pacing to prolong QT interval and increase transmural dispersion of repolarization: does resynchronization therapy pose a risk for patients predisposed to long QT or torsade de pointes? *Circulation* 2003;107:740–746.
12. Roque C, Trevisi N, Silberbauer J, et al. Electrical storm induced by cardiac resynchronization therapy is determined by pacing on epicardial scar and can be successfully managed by catheter ablation. *Circ Arrhythm Electrophysiol* 2014;7:1064–1069.
13. O'Donnell D, Wisnoskey B, Badie N, et al. Electrical synchronization achieved by multipoint pacing combined with dynamic atrioventricular delay. *J Interv Card Electrophysiol* 2021;61:453–460.
14. Varma N, Hu Y, Connolly AT, et al. Gain in real-world cardiac resynchronization therapy efficacy with SyncAV dynamic optimization: heart failure hospitalizations and costs. *Heart Rhythm* 2021;18:1577–1585.