AV conduction mode switch in a leadless pacemaker potentially contributing to ventricular fibrillation

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Introduction

Leadless pacemakers, consisting of a miniaturized system entirely implanted in the right ventricle, have been available for several years.[1] While able to mitigate lead- and pocket-related complications associated with conventional transvenous pacemakers, initial iterations of these devices were only able to provide equivalent functionality of a single-chamber pacemaker with ventricular sensing and pacing.[1] Thus, these devices were generally limited to patients with permanent atrial fibrillation.

More recently, leadless pacemakers with the ability to mechanically sense atrial activation via an accelerometer, despite being implanted in the ventricle, have been developed.[2] As a result, these leadless pacemakers are able to provide a degree of atrial sensing. When programmed VDD, the Micra AV leadless pacemaker (Medtronic, Minneapolis, MN) achieves significantly greater atrioventricular (AV) synchrony during sinus rhythm compared to a standard VVI leadless pacemaker.[2,3]

In order to minimize right ventricular pacing and improve battery longevity, the Micra AV includes an "AV Conduction Mode Switch" algorithm.[4] We present a case of potential harm arising from activation of this algorithm.

KEY TEACHING POINTS

- The Micra AV (Medtronic, Minneapolis, MN) is a leadless pacemaker with a novel mechanism of atrial sensing, which uses an accelerometer to mechanically detect atrial systole. This device contains a few unique algorithms not found in conventional transvenous pacemakers.
- The AV Conduction Mode Switch algorithm may allow the device to revert to VVI 40 for a significant amount of time, regardless of the programmed lower limit. In its current format this algorithm should be turned off at implant to prevent bradycardia-induced polymorphic ventricular tachycardia / ventricular fibrillation.
- It is important to be aware of and understand the algorithms that are available and activated on a given cardiac device to maximize potential benefit from device therapy as well as prevent potential harm.

Case report

A 28-year-old previously healthy male patient presented to a peripheral hospital with a 9-day history of fevers and constitutional symptoms. An ejection systolic murmur was noted, and a transthoracic echocardiogram demonstrated a bicuspid aortic valve with moderate-to-severe stenosis, a large mobile mass attached to the tricuspid valve, and appearances suspicious for an aortic root abscess. Multiple blood cultures were positive for *Staphylococcus lugdunensis*. A transesophageal echocardiogram demonstrated mobile vegetations on the aortic, mitral, and tricuspid valves, and confirmed an aortic root abscess. He was urgently transferred to our quaternary cardiology center.

Following initial medical stabilization, he was taken to the operating theater. Intraoperatively, a turbid pericardial effusion and extensive pancarditis with a very large vegetation burden was found. Extensive surgery was required, including a Commando operation with an aortic root conduit with a mechanical valve, a mechanical mitral valve replacement, and a bioprosthetic tricuspid valve replacement. Reconstruction was performed on the back table with the reconstructed heart then reimplanted, as previously described at our institution.[5] Temporary epicardial ventricular pacing wires were placed and the patient returned to the intensive care unit. Permanent epicardial pacing leads were not implanted owing to evidence of active infection involving the pericardial space.

KEYWORDS Leadless pacemaker; Micra AV; AV Conduction Mode Switch; Atrial sensing; Ventricular fibrillation
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On return to the intensive care unit, he was in acute anuric renal failure requiring hemodialysis support. He remained pacing dependent. Owing to the extensive nature of the surgery, it was felt that his conduction system was unlikely to recover. In view of his severe infection with blood cultures still remaining positive 5 days after surgery, as well as uncertain short- to medium-term prognosis, the decision was made to implant a Micra AV leadless pacemaker. This was performed via right femoral venous access on the eighth day after surgery, with no acute procedural complications. The device was programmed VDD 70. Parameters were excellent, with R waves sensed at 15 mV, pacing threshold 0.38 V at 0.24 ms, and impedance 550 Ω. These remained stable on the routine check the following day. After 14 days in the intensive care unit and a further 24 days in the cardiothoracic surgical ward, he was transferred back to the peripheral hospital for rehabilitation and completion of his antibiotic course. His renal function had recovered and there was no documented postoperative atrial fibrillation.

Unfortunately, the next day, he sustained a ventricular fibrillation (VF) arrest, which was witnessed on the rehabilitation ward. He was not monitored at the time. Cardiopulmonary resuscitation was performed, and a single 200 J shock terminated VF. Besides mild hypokalemia with potassium of 3.3 mmol/L, no other contributing factors were found. Specifically, he was not on any QT-prolonging drugs. An electrocardiogram showed a ventricular-paced rhythm (Figure 1) with a QT interval of 490 ms at a ventricular rate of 70 beats per minute (bpm). When accounting for the wide paced QRS complex as previously described,[6] the modified QT interval is 410 ms with corresponding corrected QT interval by the Bazett method of 442 ms.

He was transferred back to our center, where a transthoracic echocardiogram showed preserved biventricular systolic function with satisfactory function of all prosthetic valves. His blood cultures remained sterile. The leadless pacemaker was interrogated and found to be within normal limits. The cause of his cardiac arrest was not immediately clear, and he was scheduled for an upgrade to a transvenous implantable cardioverter-defibrillator (ICD).

During cardiac monitoring on the ward while awaiting the upgrade, it was noted that his ventricular rate was 45 bpm without ventricular pacing (complete heart block with ventricular escape; Figure 2). Pacemaker interrogation again showed that all sensing and pacing parameters were normal. During these episodes, device electrograms showed ventricular sensing only, with no pacing delivered (Figure 3A). Closer inspection of the rate histograms showed that for approximately 25% of the time since the implant his heart rate had been below the lower programmed rate of 70 bpm with ventricular sensing only (Figure 3B). This was owing to the AV Conduction Mode Switch algorithm being programmed on. It is highly likely that the cardiac arrest was precipitated by bradycardia-induced polymorphic ventricular tachycardia/VF.

We proceeded to implant a biventricular ICD (Cobalt cardiac resynchronization therapy defibrillator; Medtronic) and leads were implanted in the right atrium, left bundle branch area, and right ventricular apex to allow conduction system pacing. The leadless pacemaker was deactivated. He was discharged from hospital and remains well at 12 months follow-up, with no further ventricular arrhythmias. His device logs show that he is 100% ventricular paced with underlying complete heart block in follow-up.

Discussion

The AV Conduction Mode Switch algorithm on Micra AV leadless pacemakers is intended to minimize ventricular pacing burden and improve battery longevity.[4] This algorithm periodically reverts to a VVI 40 mode, and if there is intrinsic rhythm at ≥40 bpm, the device assumes that AV conduction is present and will remain in VVI 40 indefinitely as long as an intrinsic rhythm is ≥40 bpm. It reverts to VDD pacing at the

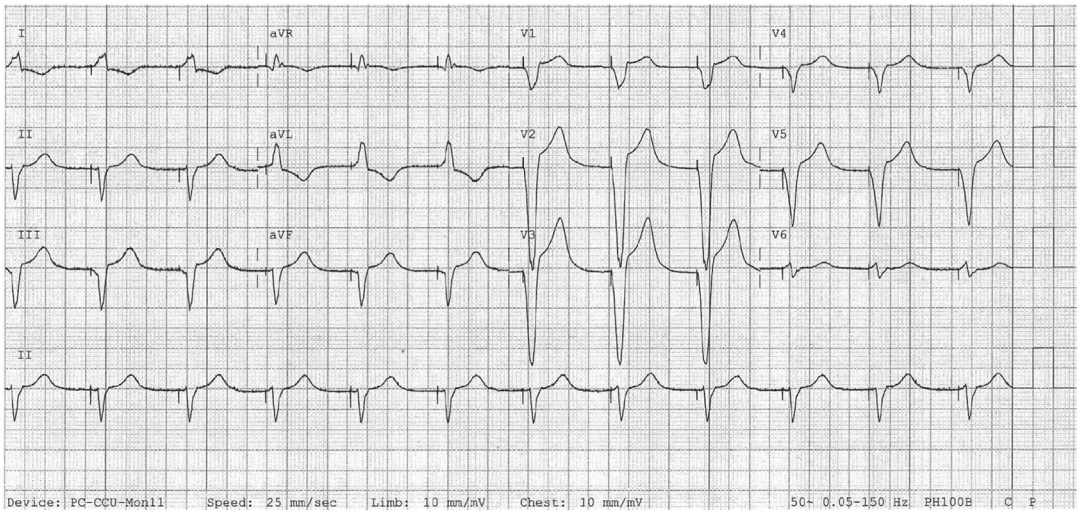

Figure 1 A 12-lead electrocardiogram recorded after presentation with ventricular fibrillation arrest. The patient is in a ventricular-paced rhythm at the programmed rate of 70 beats/min. After correcting for the QRS width and ventricular rate, the corrected QT interval is 442 ms.

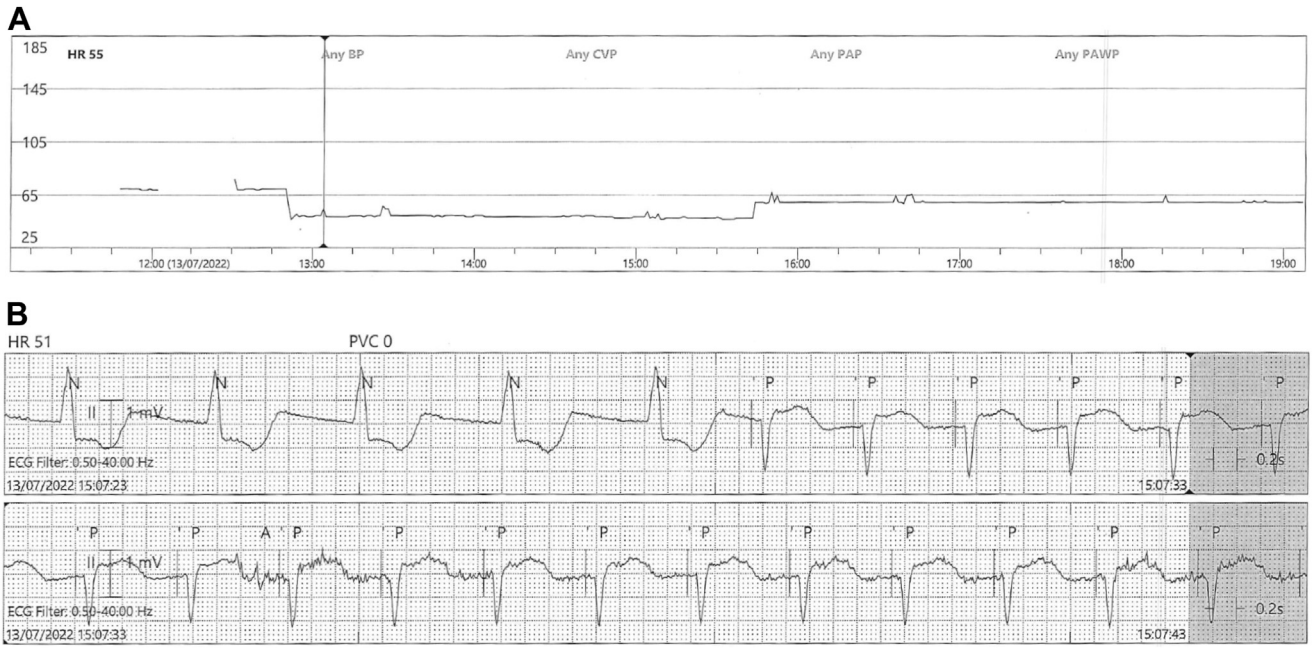

Figure 2 Data obtained from inpatient cardiac monitoring with a leadless pacemaker in situ programmed VDD 70. **A:** The heart rate trend shows an approximately 3-hour period with a heart rate of 45 beats/min. **B:** The electrocardiogram shows that pacing is not being delivered during this period, followed by pacing recommencing at the programmed rate of 70 beats/min.

programmed rate if greater than 2 of 4 beats are paced, indicating an intrinsic rhythm of <40 bpm.[4] Atrial sensing is deactivated when this algorithm is active.

In this case, while the patient did not have any significant intrinsic rhythm at the time of device implant, it appears he developed an escape rhythm at ≥40 bpm over the ensuing weeks. Therefore, during activation of the AV Conduction Mode Switch algorithm, the device reverted to a VVI 40 mode and remained in this mode for significant periods of time, as demonstrated on the rate histograms. It is almost certain that the presence of an intrinsic rhythm ≥40 bpm in this case merely indicated a ventricular escape rhythm at that rate, and not intact AV conduction. Furthermore, despite the device being programmed VDD 70, this algorithm did allow the heart rate to run at a much slower rate than the programmed lower rate. We hypothesize that VF arrest in our patient may have resulted from being allowed to remain in complete heart block without pacing. For example, this may have allowed the occurrence of long-short sequences and induction of ventricular arrhythmia.[7] This mechanism was unable to be proven definitively, however, as the Micra AV does not store electrograms.

The AV Conduction Mode Switch algorithm is programmed on by default on the Micra AV. We suggest this is inappropriate and the manufacturer should consider changing the default to off. Most patients in whom the Micra AV is implanted will be in permanent complete heart block and algorithms to reduce ventricular pacing are unnecessary. Although algorithms to promote AV synchrony and reduce unnecessary ventricular pacing are useful in patients with intermittent complete heart block, the method of sensing with the Micra AV device is different from transvenous devices—that is, mechanical vs electrical sensing of atrial activity. The Micra AV Conduction Mode Switch algorithm only looks for a ventricular rate greater than 40 bpm and ignores all atrial sensing. It assumes AV conduction but has the potential to allow prolonged periods of complete heart block (between 40 bpm and the programmed lower rate) to occur with the associated risk of polymorphic ventricular tachycardia/VF.

There is an example of another Micra AV algorithm, the Tracking Check algorithm, contributing to initiation of torsades de pointes by allowing short-long-short sequences.[8] It is therefore important to understand the algorithms that are active on the device and meticulously select the algorithms that are appropriate for a given patient.

A possible alternative approach to implantation of a transvenous ICD in this case would have been deactivation of the AV Conduction Mode Switch algorithm and implantation of a subcutaneous ICD. This would have the advantage of avoiding transvenous hardware given his history of severe endocarditis. However, as the patient had made significant clinical improvement and no longer had evidence of active infection, we did not consider that a transvenous system was contraindicated. Furthermore, tunneling a subcutaneous lead in the parasternal region may have been technically challenging owing to scar tissue related to the prior sternotomy. The transvenous cardiac resynchronization therapy defibrillator system provided additional advantages, including improved AV synchrony, avoidance of pacing-induced cardiomyopathy by provision of conduction system pacing, and elimination of the risk of adverse interaction between separate leadless pacing and subcutaneous ICD systems.

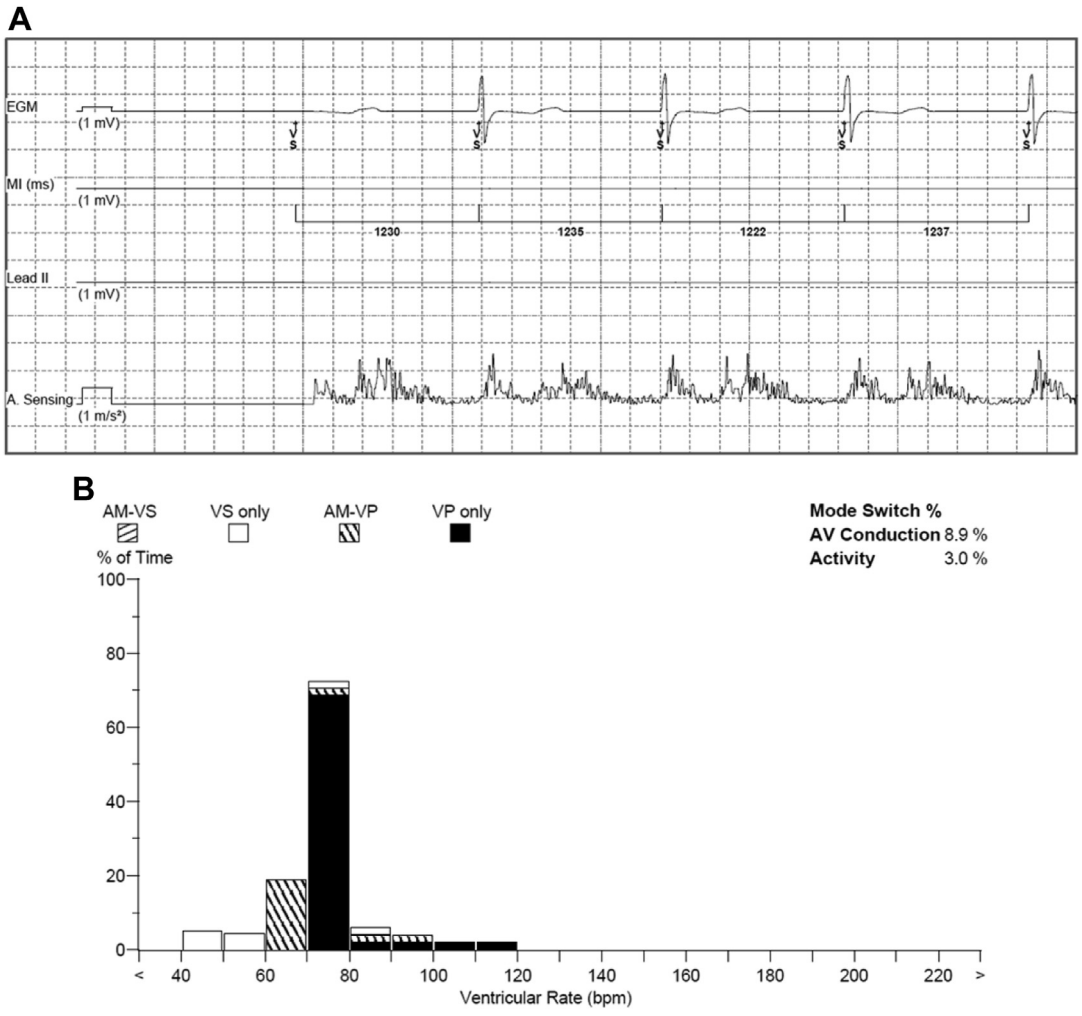

Figure 3 Interrogation of the Micra AV device (Medtronic, Minneapolis, MN) following the ventricular fibrillation arrest. **A:** Electrograms during the periods with a ventricular rate below the programmed lower limit show ventricular sensed events only. **B:** Rate histograms show that significant periods of time occur with ventricular sensing only without pacing between 40–60 beats/min, which is below the programmed pacing rate. This is consistent with behavior during activation of the AV Conduction Mode Switch algorithm.

Conclusion

Although the Micra AV provides the benefits of AV synchrony within a leadless pacing platform, and algorithms to reduce unnecessary ventricular pacing are important, it is vital to understand how these algorithms work in this novel device. In most patients currently implanted with the Micra AV, algorithms to reduce ventricular pacing are probably unnecessary and—given the potential for harm, as demonstrated by this case report—should be programmed off.

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