Automatic pacing output optimization system causes pacing failure: Two case reports

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Introduction

The automatic pacing threshold measurement and output adjustment function, ie, ventricular capture management (VCM; Medtronic, Minneapolis, MN), is found in almost all permanent pacemakers, as it ensures patient safety during unexpected increases in threshold as well as reduces battery consumption and frequency of generator replacement.[1–4] As surgeries for pacemaker generator replacement may result in complications such as lead fracture or infection, the automatic adjustment system benefits patients with a pacemaker; however, this system may also fail. Herein, we report 2 cases wherein pacing failure was attributed to the pacemaker's automatic threshold measurement and output adjustment function.

KEY TEACHING POINTS

- The automatic pacing threshold and output adjustment system is beneficial. However, it may cause life-threatening events in some patients.
- Indications for automatic pacing systems should be carefully considered, especially in pacemaker-dependent patients with highly variable pacing thresholds.
- The Holter electrocardiogram is essential in patients with pacemakers who are symptomatic because the pacemaker cannot detect errors on its own.

Case Report

Informed consent was obtained from all patients.

Case 1

The first case involved 70-year-old man with a dual-chamber pacemaker that was implanted in his left chest in 2006 for symptomatic Mobitz type 2 atrioventricular block. Pacemaker generator replacement (Adapta ADDR01; Medtronic, Minneapolis, MN) was performed in 2015. His medical history was unremarkable. He had visited our clinic regularly and was asymptomatic. The pacemaker was programmed in DDD mode with a base rate of 50 beats/min.

Since September 2021, the patient complained of persistent dizziness and shortness of breath. On 12-lead electrocardiogram (ECG), an atrial-sensed and ventricular-paced rhythm was shown, and he was pacemaker dependent (Figure 1A). Chest radiographs revealed that the atrial lead was implanted in the right atrial appendage, while the ventricular lead was implanted in the right ventricular apex (Figure 1B), which are both Medtronic tined leads (5554-53 cm and 5054-58 cm, respectively). Lead dislodgement or fracture was not evident. Holter ECG monitoring showed continuous loss of ventricular capture after the P wave, with the longest being 11.4 seconds without junctional escape rhythms (Figure 1C); this recurred throughout the day. Pacemaker interrogation revealed that the ventricular pacing burden was 100% and that the ventricular lead impedance was unchanged from previous measurements (1596 ohms). Meanwhile, the ventricular pacing threshold was 0.5 V with a pulse width of 0.4 ms, which was a good value. The ventricular pacing output was programmed with VCM. The output safety margin was programmed at 1.5 times the measured threshold, while the minimum adjusted output was programmed at 1.5 V with a pulse width of 0.4 ms. Hence, the ventricular pacing output was 1.5 V with a pulse width of 0.4 ms. Ventricular sensitivity was set to 2.8 mV, as no intrinsic R waves were observed owing to atrioventricular block without escape rhythm. Far-field sensing of the P wave was not evident. Additionally, pacemaker recordings did not show high-rate episodes that were consistent with electromagnetic compatibility, and noise signals due to upper limb movement were not detected. When VCM threshold

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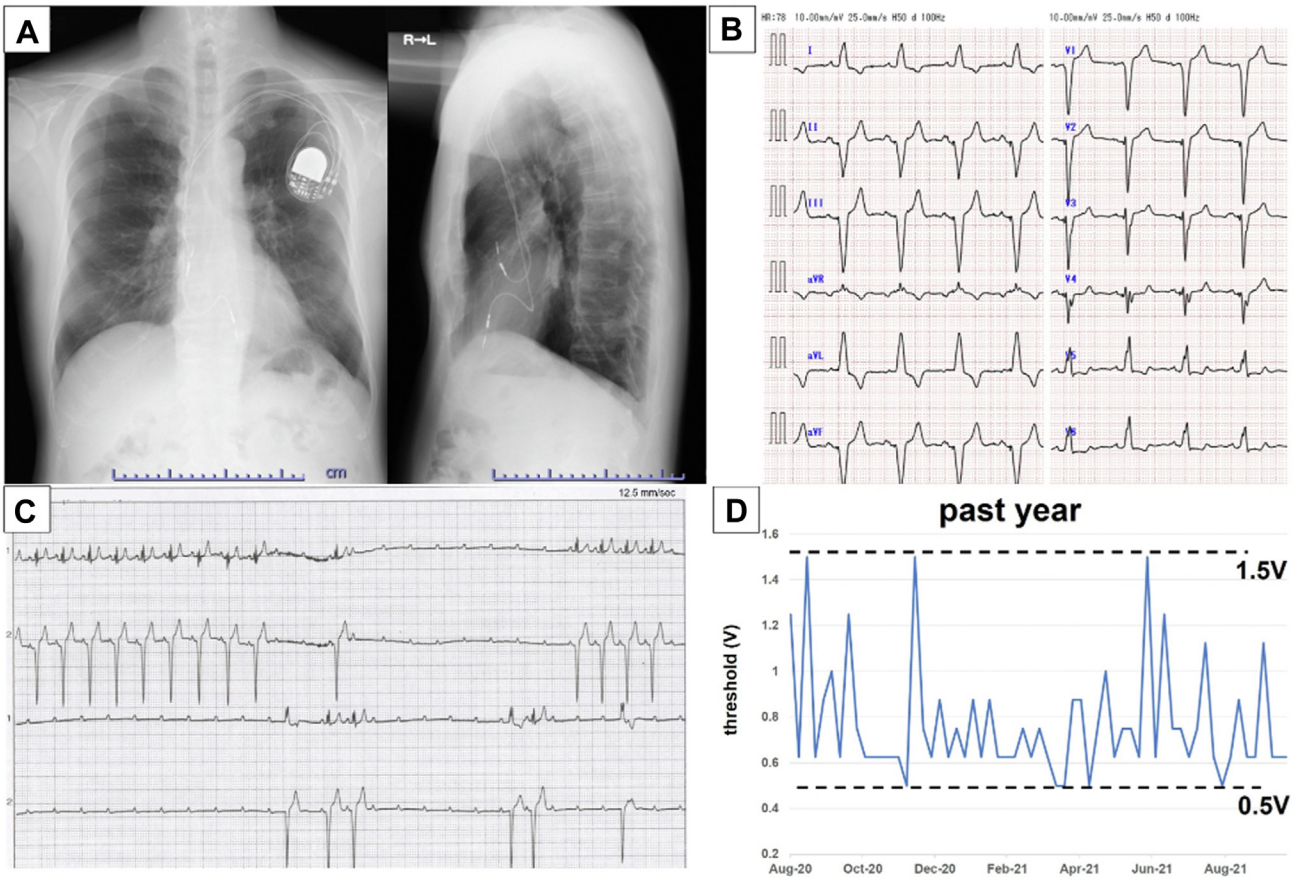

Figure 1 **A:** Chest radiograph showing the ventricular lead in the right ventricular apex and the atrial lead in the right atrial appendage. **B:** A 12-lead electrocardiogram showing the atrial-sensed and ventricular-paced rhythm. **C:** Holter electrocardiogram showing ventricular capture loss. The longest pause was 11.4 seconds. **D:** Variation of the ventricular pacing threshold in case 1 that was recorded every 24 hours for the past year. The maximum pacing threshold was 1.5 V / 0.4 ms, and the minimum was 0.5 V / 0.4 ms.

recordings over the past year were reviewed, we found that these varied widely from 0.5 V at the bottom to 1.5 V at the top (Figure 1D). We shared information about this case with the company representatives; however, no conclusive explanation was obtained. Based on our findings, long-term capture failure owing to over-sensing or lead problems was considered unlikely, and our team strongly suspected that the VCM was causing pacing failure. The VCM was turned off, and the pacemaker output was increased (3.5 V with a pulse width of 0.4 ms). Subsequently, dizziness and loss of consciousness resolved, and the Holter ECG thereafter showed no evidence of pacing failure.

We then investigated the cause of the pacing threshold fluctuation. Results of blood tests did not reveal any electrolyte imbalances or other abnormalities. Transthoracic echocardiography revealed normal cardiac function, while coronary angiography did not reveal significant stenosis. There were also no problems in the living environment that could have affected pacing. Although the cause of the threshold fluctuation remained unknown, our team concluded that pacing failure was caused by the VCM. We opted not to replace the pacemaker generator but would consider it during the follow-up, if necessary. The patient was discharged 3 days after pacemaker reprogramming. We monitored the threshold at the pacemaker clinic for 18 months after discharge and concluded that we could safely use the VCM. We turned it on, with twice the output safety margin programmed than the measured threshold, whereas the minimum adjusted output was programmed at 2.5 V with a pulse width of 0.4 ms. The patient was monitored for the next 8 months, and no symptoms or evidence of pacing failure were noted.

Case 2

The second case involved an 87-year-old man with a dual-chamber pacemaker implanted in 2004 for complete atrioventricular block; the generator (Adapta ADDRL1; Medtronic, Minneapolis, MN) was replaced in 2012. He had coronary vasospasm, hypertension, and dyslipidemia. He regularly visited our clinic and was asymptomatic. The pacemaker was programmed in VDD mode owing to the high pacing threshold of the atrial lead, and the base rate was set to 50 beats/min.

In January 2022, he was admitted because of recurrent loss of consciousness. A 12-lead ECG revealed an

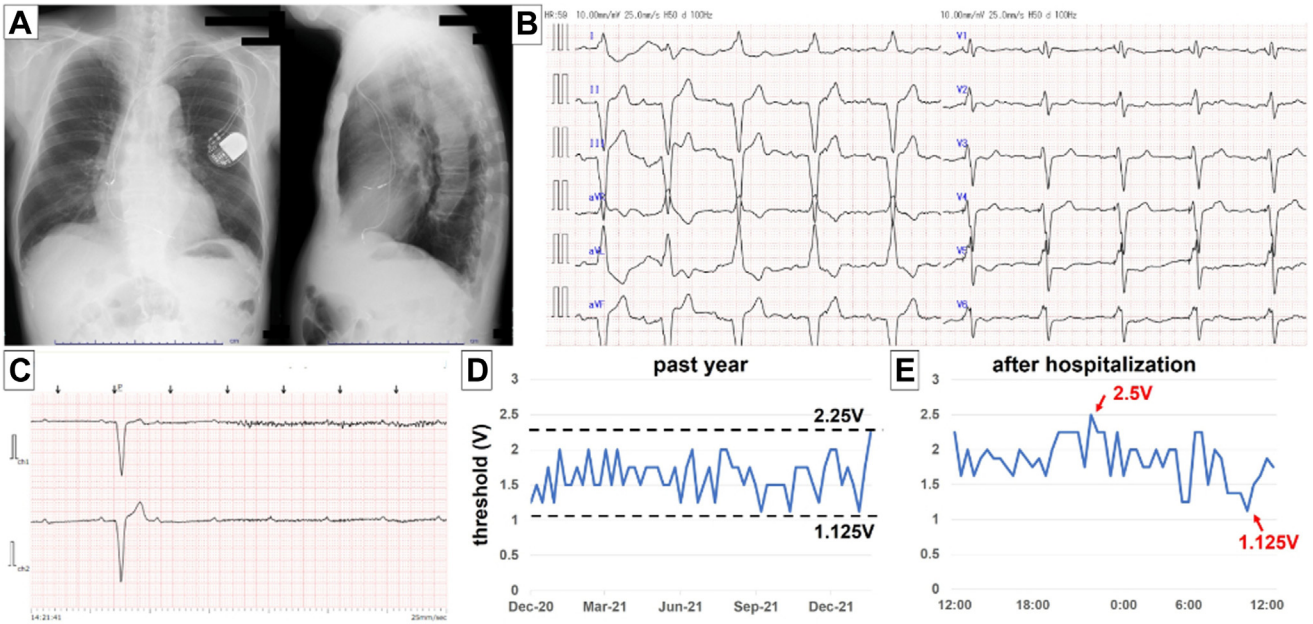

Figure 2 **A:** Chest radiograph showing the ventricular lead in the right ventricular apex and the atrial lead in the right atrial appendage. **B:** A 12-lead electrocardiogram showing the atrial-sensed and ventricular-paced rhythm. **C:** Holter electrocardiogram showing repeated loss of ventricular pacing capture. **D:** Variation of the ventricular pacing threshold in case 2 that was recorded every 24 hours for the past year. The maximum threshold was 2.25 V / 0.4 ms, and the minimum was 1.125 V / 0.4 ms. **E:** Variation of the ventricular pacing threshold in case 2 that was recorded every 30 minutes for 24 hours after admission. The maximum threshold reached 2.5 V / 0.4 ms.

atrial-sensed and ventricular-paced rhythm (Figure 2A), and he was pacemaker dependent. Chest radiographs revealed that the atrial lead was implanted in the right atrial appendage, while the ventricular lead was implanted in the right ventricular apex; both were Medtronic tined leads (5554-45 cm and 5054-52 cm, respectively). Lead dislodgement or fracture was not evident (Figure 2B). Pacemaker interrogation showed that the ventricular pacing burden was 100%. The ventricular lead impedance was 1172 ohms, which was unchanged from previous measurements, and the ventricular pacing threshold was 1.0 V with a pulse width of 0.4 ms, which was a good value. The ventricular pacing output was programmed with the VCM, the output margin was set to 1.5 times the measured threshold, and the minimum output was set to 1.5 V, resulting in a ventricular pacing output of 2.0 V with a pulse width of 0.4 ms. Ventricular sensitivity was set to 2.8 mV, as no intrinsic R waves were observed in the atrioventricular block. As in case 1, pacemaker recordings did not reveal lead malfunction. However, Holter ECG monitoring after hospitalization showed that ventricular capture after the P wave was continuously lost, similar to that in case 1 (Figure 2C), and recurred throughout the day. Additionally, there were 288 pauses longer than 2 seconds reflecting pacing failure, with the longest pause being 16.5 seconds without an escape rhythm. When the pacing threshold variations over the past year were reviewed, we found large daily variations ranging from 1.125 V to 2.25 V (Figure 2D). We then reprogrammed the ventricular pacing threshold measurement interval to every 30 minutes, and the threshold fluctuation was checked. Surprisingly, we confirmed that there was a large daily fluctuation of 1.125–2.5 V, which was similar to the set output (Figure 2E).

Although investigations were similar to those in case 1, we did not identify any abnormalities that could affect the pacing threshold. We shared information with the company representatives, but no conclusive explanation was obtained. Hence, we reprogrammed the pacemaker settings and increased the output (3.0 V with a pulse width of 0.4 ms), resulting in resolution of symptoms and pacing failure. We also identified the VCM function as the cause of pacing failure in this case. As in case 1, we did not replace the pacemaker generator. Based on the measured threshold fluctuation after admission and keeping case 1 in mind, we activated the VCM function after 3 days of patient admission, setting the output safety margin twice to the measured threshold and the minimum adjusted output to 3.0 V with a pulse width of 0.4 ms. The patient was discharged 4 days later. We followed the patient for the next 8 months and confirmed that the VCM was functioning properly.

Discussion

Automatic measurements of the pacing threshold and optimization of the output system effectively reduce unnecessary ventricular pacing, reducing battery depletion and frequency of generator replacements. This system also detects the evoked response after the pacing stimulus as well as determines the pacing threshold. Currently, almost all pacemakers use an automatic output adjustment system. A previous study

Table 1 Comparison of pacemaker automatic threshold measurement and output adjustment functions

	Timing of output adjustment	Method of output adjustment	Backup pulse
Ventricular Capture Management (Medtronic)	Thresholds are measured at programmed time intervals, but the output is adjusted once a day (Adapta) Both threshold measurements and output adjustments occur once a day at 1 AM (Azure and Advisa)	1.5 to 3.0 times the measured threshold. If it is 5 V or more, pacing is at 5.0 V/1.0 ms	None
V. Auto Capture (Abbott)	Every 8 or 24 h, or when 2 consecutive LOCs are detected	0.25 V above the measured threshold	Beat-to-beat myocardial capture is verified. In case of LOC, the output is adjusted to 5.0 V
Right Ventricular Automatic Capture (Boston)	Every 21 h or when LOC is confirmed for 2 cycles out of 4 beats	0.5 V above the measured threshold	Beat-to-beat myocardial capture is verified. In case of LOC, the output is adjusted to 1.5 V above the previously measured threshold
Ventricular Capture Control (Biotronik)	Every 0.1–24 h or at the programmed time	0.3–1.2 V above the measured threshold	Beat-to-beat myocardial capture is verified. In case of LOC, the pulse width is extended to 1.0 ms
Right Ventricular Auto Threshold (MicroPort)	Every 6 h	Twice the measured threshold	None

LOC = loss of capture.

revealed that the VCM function reliably measures thresholds in almost all patients, and that the use of an automatic pacing system reduces ventricular pacing and potentially prolongs device longevity.[5] However, we experienced 2 cases of pacemaker failure due to the VCM. With the VCM Adapta™ pacemaker models, ventricular pacing thresholds can be measured at programmed time intervals, but its output can only be adjusted once per day, and a backup pulse function is absent in the event of pacing capture failure (Table 1). Even if a threshold change occurs between threshold measurements, the pacemaker may be unable to detect it. In pacemaker-dependent patients, this increases the risk of prolonged cardiac arrest, which may result in sudden death or serious events. In a previous study, threshold changes of $\geq$1.0 V were observed in 7.5% of patients during automatic threshold measurements.[6] For pacemakers that cannot perform automatic beat-to-beat backup pulse, pacing failure may occur between the output adjustment intervals in patients with large pacing threshold variations. Although cases of pacing failure owing to automatic optimization of the pacing output system have occurred,[7,8] to the best of our knowledge this is the first report of multiple cases of pacing failure owing to the automatic optimization of the pacing output system. Although the number of reports is limited, we have experienced similar cases at a single institution in a short period of time; therefore, it can be assumed that there may be many similar cases prevalent globally. In patients with nonspecific symptoms such as dizziness, as in case 1, the cause of pacing failure may not be identified, and appropriate treatment may not be provided. We must recognize that the pacemaker itself may not detect abnormalities. Hence, if a patient presents with nonspecific symptoms, it is important to conduct additional diagnostics aside from pacemaker interrogation, including Holter ECG monitoring.

The causes of the pacing threshold fluctuation were unknown in both cases. The patient in case 2 was being managed for vasospastic angina, and it is possible that myocardial ischemia influenced the pacing threshold change, although there was no obvious chest pain or ST-T segment changes on ECG or Holter ECG. Hence, clinicians must be cautious when using VCM in patients with underlying diseases that may cause pacing threshold fluctuations. Although symptoms resolved after altering the output settings, close monitoring and follow-up of patients are warranted.

Conclusion

We experienced 2 rare cases of pacing failure while using the VCM system, which is the automatic pacing threshold measurement and power adjustment function. The automatic power adjustment function should be used with caution in patients with large threshold variations, especially in pacemaker-dependent patients.

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