Intrinsic anti-tachycardia pacing terminated ventricular tachycardia resistant to traditional anti-tachycardia pacing

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ABSTRACT
Implantable cardioverter-defibrillators (ICDs) serve to reduce the risk of sudden death; however, ICD shocks worsen patient prognosis. Therefore, attempts have been made to terminate life-threatening arrhythmias without ICD shocks. A 71-year-old man with non-ischemic cardiomyopathy, who previously underwent cardiac resynchronization therapy-defibrillator (CRT-D) placement, was hospitalized for ventricular tachyarrhythmia (VT) that was refractory to traditional anti-tachycardia pacing (ATP). Endocardial and epicardial ablation failed to prevent VT recurrence. Since the CRT-D battery was exhausted, it was replaced with a Cobalt™ XT HF CRT-D (Medtronic, Minneapolis, MN, USA), and the intrinsic ATP (iATP) algorithm was employed. Although VT recurred frequently, recurrent VTs were terminated by the iATP, which created a conduction block in the circuit without VT acceleration or shock. This is the first reported case wherein an iATP algorithm was effective against VT resistant to traditional anti-tachycardia pacing. This novel ATP algorithm has the potential to terminate refractory VT without ICD shocks and provide a better prognosis.

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1. Introduction
Implantable cardioverter-defibrillators (ICDs) reduce the risk of sudden death [1]; however, ICD shocks for arrhythmias are associated with a poor prognosis [2]. Thus, various attempts have been made to terminate life-threatening arrhythmias without ICD shocks, including the use of anti-tachycardia pacing (ATP). Previous reports have shown the effectiveness of an automated ATP algorithm designed in accordance with electrophysiological principles [3].

Intrinsic ATP (iATP) is a novel, auto-programmed ATP algorithm that designs each subsequent ATP sequence by analyzing the post-pacing interval following a failed ATP sequence in real-time. First, an iATP optimizes the number of pulses required to reach the ventricular tachycardia (VT) circuit. Then, it estimates the refractory period during VT and shortens the S2 interval for each sequence. When the post-pacing interval is shorter than the length of the VT cycle, S2 stimulation is not captured, and an S3 pulse is added. Thus, the antidromic wave collides with the active front of the previous stimulated beat, and the orthodromic wave is blocked by the relative refractory tail (Fig. 1). Although the efficacy of iATPs has been reported, their effectiveness against VTs resistant to traditional ATP has not yet been reported [4]. Herein, we report a case in which iATP was effective against recurrent VT refractory to a traditional burst ATP algorithm.

2. Case report
A 71-year-old Japanese man underwent cardiac resynchronization therapy-defibrillator (CRT-D) placement to treat sustained VT and complete atrioventricular block in the presence of a non-ischemic cardiomyopathy. Subsequently, transcatheter ablation was performed twice for recurrent VT. A low-voltage zone was identified in the postero-basal left ventricular area and near the mitral valve annulus; thus, radiofrequency catheter ablation (RFCA) was performed.
Two years later, the patient was admitted for VT ablation because traditional burst ATP (ATP 1: 88% × 10 pulses, three sets with a 10-ms decrement; ATP 2: 84% × 10 pulses, three sets with a 10-ms decrement; and ATP 3: 78% × 10 pulses, three sets with a 10-ms decrement) could not terminate the VT (cycle length [CL]: 410 ms) and ICD shocks were delivered (Fig. 2A and B). Endocardial and epicardial ablation were ineffective; therefore, another session of RFCA was scheduled.

In the interim, because the CRT-D battery was exhausted, the impulse generator was replaced with a Cobalt™ XT HF (Medtronic, Minneapolis, MN, USA). We introduced the iATP algorithm into the VT therapy zone. A subsequent episode of VT with a CL of 440 ms and a similar intracardiac electrogram was detected in the VT zone, and iATP was performed. In the sixth iATP sequence, S3 stimulation terminated the VT and prevented an ICD shock. Within 2 weeks of introducing iATP, 50 VT episodes were recorded; of these, 49 were terminated by iATP, while one was spontaneously terminated without iATP. Another session of RFCA had failed, and hence, the patient was followed up at an outpatient clinic.

3. Discussion

In our case, because traditional burst ATP could not terminate the VTs, the patient received many ICD shocks. Conversely, iATP could successfully terminate the VT without any shock treatment. A detailed analysis of the intracardiac electrogram revealed that the VT CL was 440 ms, and the first sequence of iATP involved six S1 pulses (390 ms; 88% of the VT CL) followed by an S2 pulse (330 ms) (Fig. 3A). The post-pacing interval (PPI) was 500 ms, and ATP could reset the VT without its termination. The propagation time from the pacing site to the VT circuit, calculated based on the PPI, was 30 ms ([500 ÷ 440] ÷ 2); this was shorter than the nominal value of 150 ms. The number of S1 pulses was reduced to four. S2 was gradually shortened from 300 ms to 250 ms during the second and fourth sequences; however, this did not terminate the VT (Fig. 3B). The orthodromic wave was not blocked by the relative refractory tail (Fig. 3D). In the fifth sequence with an S2 of 230 ms, the PPI was 250 ms; this was shorter than the VT CL, indicating that S2 stimulation had lost capture (Fig. 3C and E). In the sixth sequence, four S1 pulses (380 ms), followed by S2 (270 ms) and S3 (230 ms) pulses,
created an antidromic block in the VT circuit, and the VT was terminated successfully (Fig. 4). The pacing CL of the S1 pulses was decreased from 390 ms to 380 ms because the VT CL changed from 440 ms to 430 ms after the fifth sequence. Through this case, it was demonstrated that iATP calculates the appropriate number of S1 pulses from the propagation time between the pacing site and the VT circuit without VT acceleration and that S2 or S3 extra-stimulation terminates VT efficiently by creating a conduction block in the VT circuit. The case by Morishima et al. demonstrated one advantage of the iATP algorithm, in which the VT had a short CL of 280 ms, and the increased number of S1 stimulations achieved VT termination [4]. In contrast, our case highlighted another advantage of the iATP, which was the ability to adjust the coupling interval of the extra stimulations (S2 and S3) in accordance with the estimated ventricular refractory period. Swenson DJ et al. reported a new automated anti-tachycardia pacing (AATP) therapy that could terminate VT episodes that burst ATP failed to terminate in a virtual study using computer modeling. They reported that a less aggressive S1 stimulation at 88% of the VT CL followed by aggressive S2 and S3 stimulations improved efficacy without increasing the acceleration rate [5]. In our case, the ventricular effective refractory period (ERP) was short (230 ≤ ERP < 250 ms at a basic cycle of 390 ms) as compared to the VT CL, which was considered to be a major reason for the failed

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**Fig. 3.** ICD records of the first sequence (A), second sequence (B), and fifth sequence (C). Schema of the VT circuit and relationship between the refractory period and stimulus (D and E). The red arrow represents the wavefront of S1, the time between the head and tail is the excitable gap, and the blue area of the VT circuit represents the region that is out of the refractory period. In the first and second sequences, the orthodromic wave was not blocked by the relative refractory tail because the S1–S2 interval is long (D). In the fifth sequence, S2 could not reach the VT circuit (E).
termination by the traditional burst ATP. To create a conduction block in the orthodromic direction by burst or ramp ATP, a short pacing interval might have been needed, though that aggressive ATP therapy might have accelerated the tachycardia.

In conclusion, this is the first reported case wherein iATP was observed to be an effective treatment for VT that was not successfully terminated by traditional burst ATP. This novel ATP algorithm may reduce the need for ICD shocks and improve patient prognosis in real-world settings.

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Hikaru Hagiwara: Data curation, Writing- Original draft preparation Masaya Watanabe: Conceptualization, Supervision Rui Kamada: Visualization, Investigation Toshihisa Anzai: Writing-Reviewing and Editing.

Declaration of competing interest
The authors declare that they have no known competing financial interests or personal relationships that could influence the work reported in this paper.

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