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Implantable Cardiac Pacemaker

Case studies based on Medtronic Tracings

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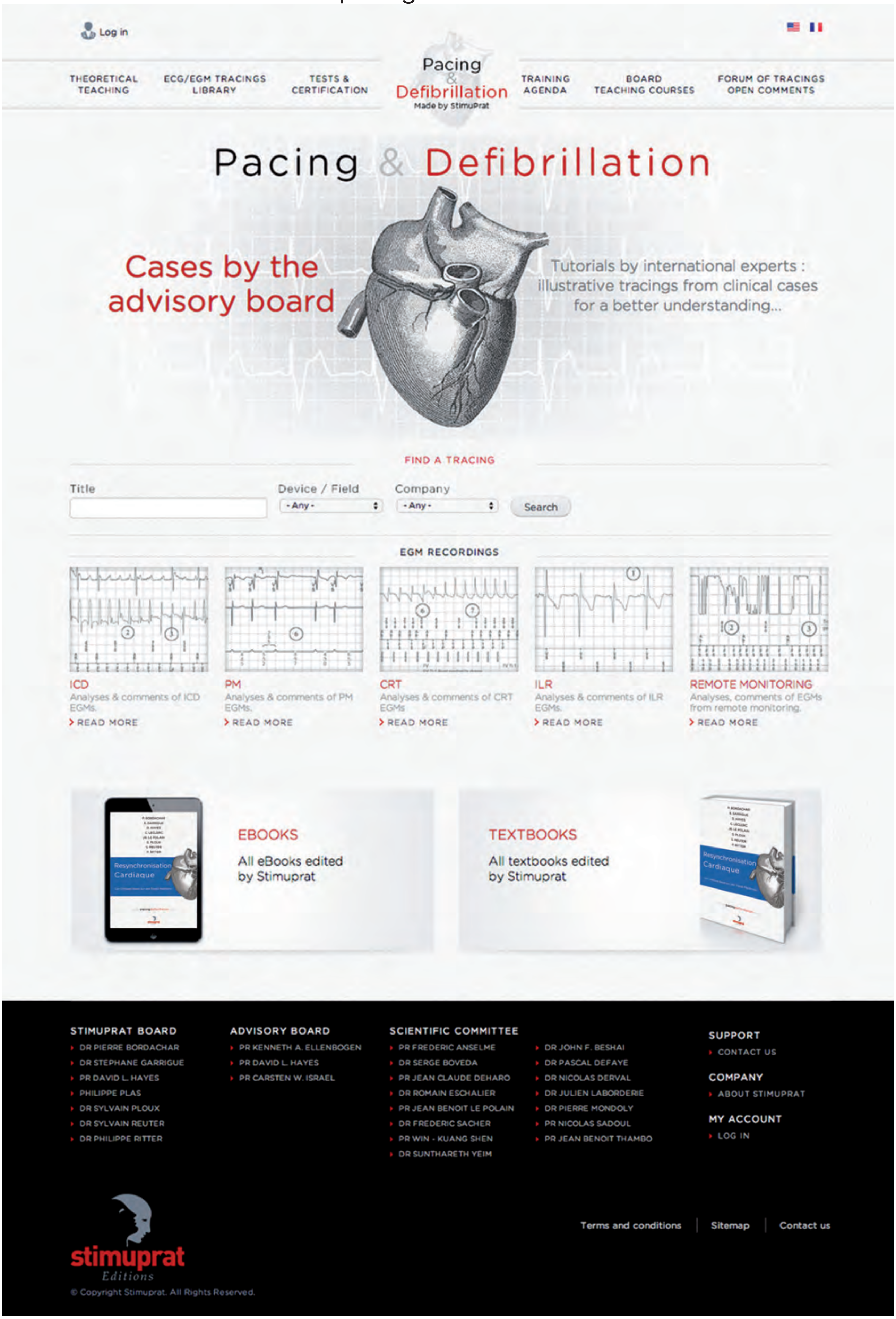

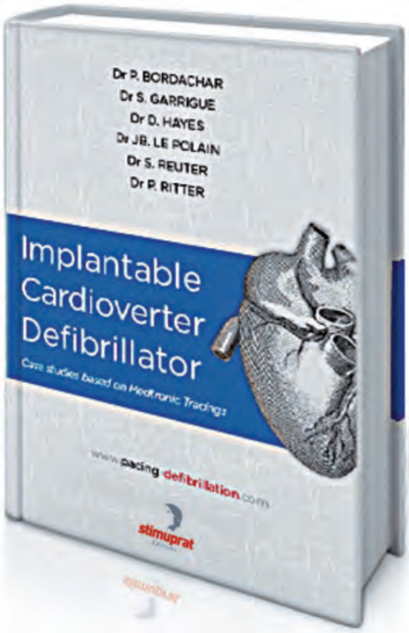

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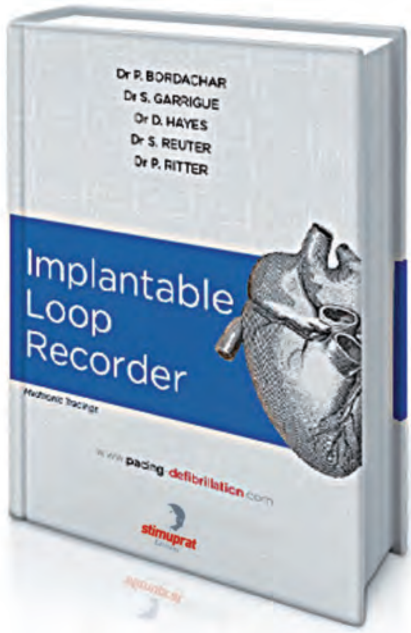

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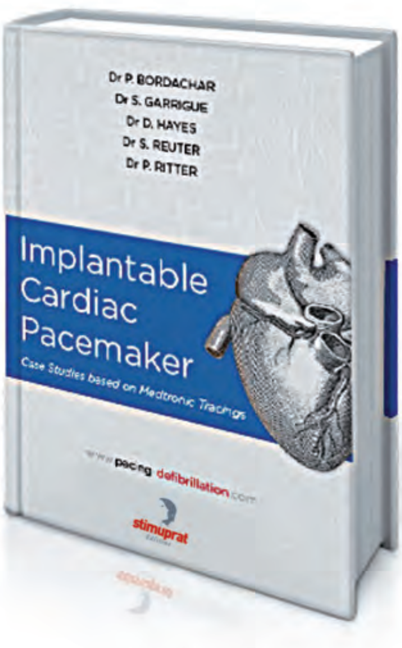
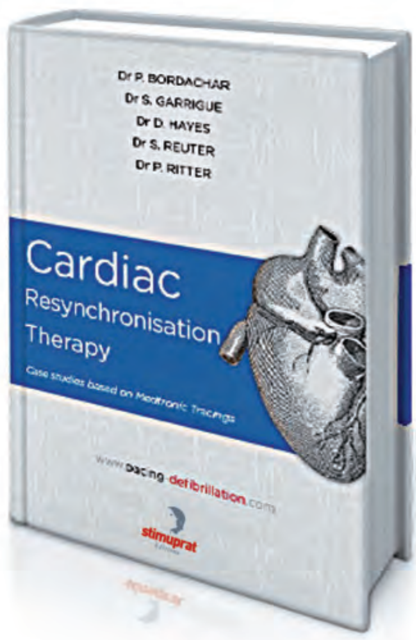


PM



CRT

Summary

Preface

At nearly 50 years of age, permanent cardiac pacing is an emblematic representative of the biomedical industry's spectacular evolution. The truly remarkable soar of its technological progress, however, began in the 1980s, when microprocessors were embedded in the pulse generator. Since then, the invention of new functions by engineers and physicians has lead to the design of today's devices, which fulfill the needs of the vast majority of pacemaker recipients. The galloping evolution of the last 30 years has given birth to highly complex devices capable of producing confusing electrocardiographic (ECG) tracings unless interpreted by an observer highly familiar with their functions. Besides the generic functions, which are incorporated in all pacemakers, specific algorithms have been added that distinguish particular models or generations of devices. The production of a new generation of pulse generators, on average every 18 months, with innovative functions, mandates a constant and accelerated update of the users' knowledge and ongoing continuing education, whether it be a young practitioner in need of rapid learning of basic or advanced pacing, or a seasoned expert keenly interested in offering patients the best of the latest functional discoveries.

We composed this monograph in a didactic spirit, with the regular objective to compose a chapter explaining in a detailed fashion, the theoretical basis of the device functions, before illustrating comments with ECG tracings along with event markers. The detailed interpretation of each tracing is didactic and followed by practical comments and solutions to the illustrated queries, offered along with a reminder of good practices. The work is divided in 5 sections:

1. Detailed presentation of each pacing mode, with their advantages, shortcomings and indications;
2. Principal pacing functions, including capture and sensing and their programming basics;
3. The stages of dual chamber pacing and programming recommendations and management of electronic re-entrant tachycardias;
4. The behavior of dual chamber pacemakers during effort and the optimization of the atrioventricular (AV) synchronization settings;
5. The management of atrial arrhythmias in dual chamber pacemakers and preventive functions.

For the reasons described, this document needs to be scalable and will be updated over time with new ECG tracings, keeping in mind that it is but one link in the series of documents composed by the authors, which include implantable defibrillators, implantable loop recorders and cardiac resynchronization.

Interrogation of Cardiac Pacemaker

Interrogation of Cardiac Pacemaker

The follow-up of a permanent cardiac pacemaker recipient includes a clinical examination, the recording of an ECG, with and without the placement of a magnet over the pulse generator, and its interrogation with a model-specific programmer. The frequency of interrogations depends on the model implanted, the patient's characteristics, the presence of symptoms, the age of the device, the medical center's practices and, the ability to follow remotely.
The first follow-up and interrogation, performed at the end of the implantation procedure, are usually followed by a verification of the device's functions before discharge of the patient from the hospital. The time spent in the hospital can be used to teach the patient the pacemaker's function, the precautions to observe and the long-term follow-up needs. The next visit is scheduled after complete wound healing, usually between the first and third postoperative month. In the absence of new disease manifestations, further follow-ups usually take place two to four times a year, depending on the institution following the device and type of follow-up, i.e. remote vs in-office. The frequency of follow-up increases near the pulse generator's end of battery life, except when telemedicine is used. The aims of the follow-up are:

- To adapt the programming of the device to the electrophysiological and hemodynamic characteristics of its recipient;
- To optimize the pacemaker's longevity while observing an adequate safety margin;
- To identify and treat possible complications;

The interrogation of the pacemaker includes a systematic analysis of 3 types of information: a) battery status, b) implanted lead(s) function(s), and c) interrogation of the pulse generator memory, which yield information in the form of frequency histograms, percent pacing, and arrhythmia burden, as well as clinical data.

In contrast to the relatively simple follow-up of older generation single chamber devices, which offered limited functions, the interrogation of a state-of-the art pacemaker is more complex. On the other hand, the interrogation is now facilitated by the availability of automatic measurements performed directly by the pulse generator, and by an introductory screen, which displays the main data. For Medtronic pacemakers, the Quick Look screen II appears automatically at the launch of the programmer in the beginning of the patient session. It provides a summary of the most important indicators of the system's functions and of the patient status since the last follow-up, and includes links toward more detailed information regarding the device status and diagnostics stored in the device memory.
The interrogation of a pacemaker proceeds in a relatively standardized manner. It is recommended to print and file the initial and final programming of the device in the patient's records, and to provide the patient with a copy of the final programming.

Various elements are analyzed at each follow-up

1 - Battery consumption

Rudiments of electricity theory

The relationship between energy delivered with each pulse and amplitude, pulse width and impedance is defined by the formula: $E=(U^2/R) \times PW \times 100$
E= energy in joule; U=amplitude in Volt; R=impedance in Ohm; PW= pulse width in ms

- for a pulse of 2.5V/ 0.5 ms with an impedance of 500 Ohms: $E = (2.5^2/500) \times 0.5 \times 100 = 6.25$
- for a pulse of 5V/0.5 ms with an impedance of 500 Ohms: $E = (5^2/500) \times 0.5 \times 100 = 25$

This formula highlights the increase in energy proportionally to the square of amplitude and proportionally to the pulse duration:

- by doubling the output amplitude, the energy consumed is multiplied by 4;
- by doubling the pulse width, the energy consumed is multiplied by only 2.

A iodine-lithium battery is included in all state-of-the-art pacemakers. The output voltage of a new battery is 2.8 V, delivered constantly. Its wear is associated with an increase in the internal resistance and a parallel decrease in output voltage, which is an end of life criterion.

The iodine-lithium battery of pulse generators has a nominal capacity of 0.8 – 2.0 ampere/hour (amp/h). A battery with a capacity of 1 amp/h delivers continuously:

- 1 amp over 1 hour
- 10 mA over 100 hours
- 10 A over 100,000 hours

100,000 hours = 11.4 years

The factors which influence the pacemaker's longevity are:

- pulse amplitude
- pulse width
- lead impedance
- pacing rate
- percent pacing
- memories
- telemetry
- battery capacity

Lithium-iodine batteries do not wear suddenly. The end-of-life indicators allow sufficient time for the reprogramming and planning of the pulse generator replacement.

Evaluation of battery depletion during follow-up

Medtronic pacemakers measure the battery voltage automatically several times a day. At midnight, it automatically calculates the daily battery voltage by averaging the measurements made in the last 24 h. The most recent automatic measurement of the battery voltage is displayed on the screen.

Two weeks after implant of the device, the programmer can estimate the remaining number of years, which should elapse before the battery reaches the elective replacement indicator (ERI). The estimates of life expectancy are based on the history of the battery voltage measurements made by the device since its implantation. The maximum, minimum and mean estimated, residual battery life expectancies are displayed on the screen, based on a statistical analysis of the accelerated depletion data of the battery. The maximum and minimum estimates of residual life expectancy correspond to the 95th percentile values calculated from the distribution of these data (95% of the devices reach ERI before the maximum value and 95% reach ERI after the minimum value displayed). When 3 consecutive, automatic daily measurements of the battery voltage are below or equal to the recommended date of replacement, the programmer displays the ERI symbol and the date at which it has been reached.
The expected duration of service of the pulse generator after the onset of ERI, defined as the prolonged service period (PSP), is 6 months (180 days). Once the first 90 days of PSP have elapsed, the pacing mode is automatically switched to VVI at a rate of 65 bpm. All pacing settings can be reprogrammed, including the pacing mode and rate. However, the reprogramming of the pacing parameters incurs a risk of shortening the interval between ERI and the end of service (EOS).
Once the 180-day PSP has expired, the device has reached the end of service and the programmer displays the EOS symbol, at which point the pacemaker: a) is unlikely to pace, sense and deliver therapy accurately, and b) should be replaced emergently.
In practice, the pulse generator should be replaced as soon as ERI has been reached, particularly if the patient is pacemaker-dependent.

2 - Leads function

Analysis of the function of implanted leads is an important step of the interrogation. Various tests are performed in search of a possible lead dislodgement, a disconnection, an insulation breakdown or a fracture of the conductor coil. Furthermore, measurements of the sensing and capture thresholds allow an adaptation of the programming to guarantee the patient's safety while preventing an excessive consumption of energy.

Automatic measurements

The programmer displays a detailed history of the automatic measurements of impedance, capture threshold and sensing.
The leads' trend graphs displayed on the Quick Look II screen show the measurements of lead impedance, capture threshold and sensing amplitude recorded in the past 12 months.
The detailed trend graphs display up to 15 of the most recent daily measurements, and up to 80 weekly, repetitive measurements (showing the minimum, maximum and mean values for each week).

Real-time measurements

The standard interrogation of a cardiac pacemaker includes a lead impedance test, a test of the sensing functions and a test of the capture thresholds. These tests can be compared with those performed automatically to confirm their accuracy.
A verification of the lead(s) function is an indispensable step before an interrogation of the various memories, because, for example, ineffective sensing invalidates the analysis of arrhythmias by the pacemaker.
The capture threshold is measured by automatically decreasing the pacing amplitude while maintaining a fixed pulse width or, conversely, by decreasing the pulse width at a fixed amplitude.
The lead(s) impedance test ascertains the integrity of the implanted lead system by measuring the impedance of the atrial and/or ventricular pacing leads. The pulse generator measures the impedance without capturing the heart using low-voltage sub-threshold pulses.
The sensing test allows the temporary programming of pacing mode, AV delay and backup rate. The amplitude of the sensed signals can be measured without loss of sensing.

3 - Analysis of the pacemaker memories

Follow-up of percentage of pacing

The atrial and ventricular pacing and sensing data are shown in percentage of time during the period covered by the report, including the percentage of time during which AS-VS, AS-VP, AP-VS and AP-VP sequences occurred.

Analysis of rate histograms

The rate histograms show the percentage of time spent by the device in pacing and sensing in the various rate ranges, in increments of 10 bpm. Rates below 40 bpm are included in the "<40" and rates above 180 or 220 bpm, depending on the model, are included in the ">180" or ">220" rate ranges.

Follow-up of atrial fibrillation burden

The number of mode switch episodes and the percentage of time spent in fallback are displayed on the introductory screen. The ventricular rate histogram during episodes of atrial arrhythmias shows the sensed and paced ventricular events, which occurred during sensed atrial arrhythmias, including the cumulative time spent in the arrhythmia. This histogram might help in ascertaining the effectiveness of managing the ventricular rate and drug dosages.

Follow-up of clinical data

The Cardiac Compass, offered by the last series of pacemakers, presents an overall report of the patient's status in the last 14 months. The graphs show the time spent in AT/AF (Atrial Tachycardia/Atrial Fibrillation), the ventricular rate during AT/AF, the daily percent pacing, the mean ventricular rate, the hours of daily activities, as well as the intrathoracic impedance and the index of pulmonary overload, OptiVol. The evolution of the intrathoracic impedance allows a comparison of its mean daily measurements with the reference impedance; a change in intrathoracic impedance might be an early warning of intrapulmonary fluid accumulation.

4 - Non-systematic observations

Some observations might appear on the screen during device interrogation, which are prompted by unexpected events or measurements, or which offer programming advice. These observations, based on the analysis of the programmed parameters and the data collected since the last interrogation, might consist in:

- device status and time when it approaches ERI or EOS, or when it has re-initialized.
- status of the leads and alerts pertaining to all potential issues related to the quality of sensing and abnormal results of threshold testing.
- warnings regarding incoherent programming of the sensing and therapy settings, for example the adjustment of the settings that de-activate the therapy.
- diagnostic observations indicating the occurrence of noteworthy arrhythmic episodes.
- clinical observations warning the caregiver of an abnormal patient status, particularly low level of exercise, abnormally high heart rates, heavy arrhythmic burden or fluid accumulation.

Home Screen

Case 1: Home screen

Patient : 63 year old man implanted with an Adapta dual-chamber pacemaker for repetitive syncope associated with complete atrioventricular block.
Routine outpatient visit.
The different steps of a standard PM interrogation will be explained and developed. The Home screen provides a global view of the different parameters for optimal PM programming.

1 : Battery status
On the home screen, several indicators of battery use can be observed. First, voltage output progressively decreases with time along with the increase in pacing impedance. In this patient, voltage output of 2.78 V and an impedance reaching 345 ohms show no battery wear. Expected lifetime of the battery is estimated by use of repetitive measurements of the battery status since the patient has been implanted; maximal values (8 years), minimal values (5.5 years) and average values (7 years) of battery expected lifetime are shown on the screen. They are based on statistical analysis of accelerated battery wear measurements.

2 : Pacing leads functioning
Different graphs are shown on the screen: repetitive measurements of lead impedance, voltage pacing threshold, p-wave and R-wave sensing, recorded over the last twelve months. In this patient, the periodical measurements of atrial and ventricular pacing threshold remain unchanged for one year and are below 1 V for 0.4 ms of pulse duration. The PM periodically and automatically adapts pacing voltage amplitudes according to threshold measurements. The programmed amplitude is fixed to twice the calculated pacing threshold without going below 2V for the ventricular lead and 1.5V for the atrial lead.
In this patient, pacing thresholds are excellent and the voltage amplitude determined by the PM algorithm provides the opportunity to limit battery wear for optimal use. Pacing lead impedances are normal and stable. The atrial sensing test is periodically performed by the PM and provides a sensing threshol reaching 2.8 mV for a programmed value of 0.5mV which offers an excellent safety margin. The patient is quasi-permanently paced in the ventricles and the automatic ventricular sensing test could not be achieved. The programmed value of bipolar ventricular sensing (2.8 mV) is then fixed and most of the time it provides reliable sensing of premature ventricular complexes without noise or T-wave oversensing.

3 : Parameters summary
The home screen displays the principle programmed parameters:
Pacing mode (MVP), minimal and maximal atrial-synchronized pacing rates including maximal responsive rates, sensing and pacing AV delays. The fallback has been programmed; rate responsiveness has not been programmed during sinus rhythm but only when the fallback has been activated, inducing a DDIR pacing mode functioning (during atrial arrhythmia sensing).

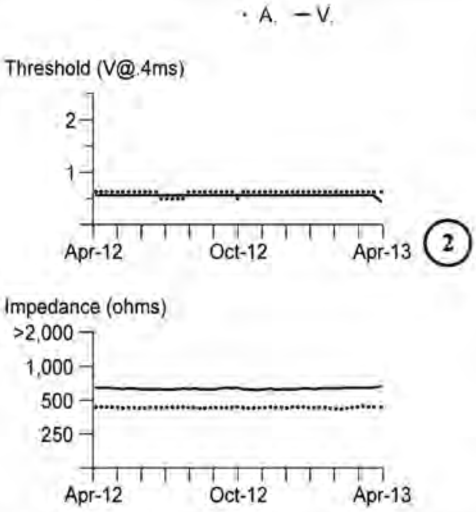
4 : Histograms and percentage of pacing
This patient appears to be pacemaker-dependent since ventricular pacing percentage almost reaches 100% (worsening nodal conduction); on the other hand, the atrial rate histogram shows an optimal distribution suggesting normal behavior of the sinus rhythm during daily-life. Consequently, there is no need for rate-responsiveness (absence of chronotropic incompetency).

- Initial Interrogation Report

Pacemaker Model: Medtronic Adapta ADDR01 Serial Number: Date of Visit:

Patient Name:	ID:	Physician:

Pacemaker Status (Implanted: 02/21/11)



Battery Status (1)

Estimated remaining longevity: Based on Past History	7 years, 5.5 - 8 years
Voltage/Impedance	2.78 V / 345 ohms

Lead Summary	**Atrial**	**Ventricular**
Measured Threshold	0.625 V at 0.40 ms	0.375 V at 0.40 ms
Date Measured	04/19/13	04/19/13
Programmed Output	1.500 V / 0.40 ms	2.000 V / 0.46 ms
Capture	Adaptive	Adaptive
Measured P / R Wave	>2.8 mV	>=80% Paced
Programmed Sensitivity	0.50 mV	2.80 mV
Measured Impedance	441 ohms	711 ohms
Lead Status	OK	OK
Lead Model		
Implanted		

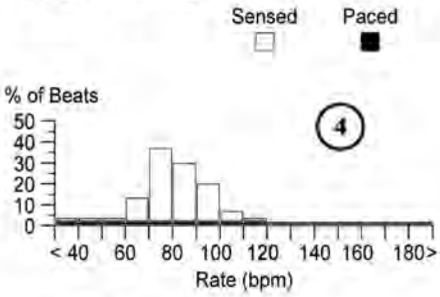
Parameter Summary

Mode	DDD	Lower Rate	60 ppm	Search AV+	Off
Mode Switch	On	Upper Tracking Rate	130 ppm	Paced AV	150 ms
Detection Rate	175 bpm	Upper Sensor Rate	130 ppm	Sensed AV	120 ms

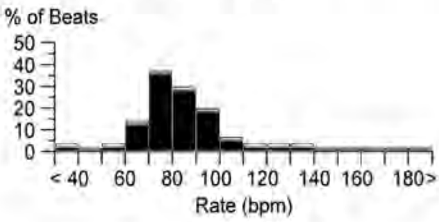
(3)

Clinical Status: 02/12/13 to 04/20/13

Atrial Long Term Histogram



Ventricular Long Term Histogram



Mode Switches: 2 (Percent of Time: < 0.1%)
Atrial High Rate Episodes: 0
Episode Trigger: Mode Switch > 30 sec
Ventricular High Rate Episodes: 0

Pacing (% of total):	
AS - VS	0.3%
AS - VP	98.8%
AP - VS	< 0.1%
AP - VP	0.9%
MVP	Off

Event Counters	
PVC singles	47,073
PVC runs	47
PAC runs	0

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Programmed parameters and EGM tracing

Case 2a: Programmed parameters

1 : Pacing mode
The MVP mode has been programmed. PM memories show that the patient is almost permanently paced in the ventricle since the last interrogation, confirming that he presents with complete atrioventricular block. Reprogramming is then needed so that the pacing mode is changed to DDD pacing instead of MVP mode.

2 : Refractory periods and blanking
The anti-ERT algorithm is not switched on in nominal; this algorithm has to be activated after PM implant.

3 : Responsiveness
As seen just above, the rate responsive algorithm has only been programmed for atrial arrhythmia-induced fallback.

4 : Atrial lead
The automatic adjustment algorithm of the pacing threshold has been activated so that the pacing amplitude is periodically adapted based on repetitive measurements of the pacing threshold (every day at 1:00 AM); results are excellent. Whatever the observed pacing threshold, a value below 1.5 V (for 0.4ms of pulse duration) cannot be automatically programmed by the PM.
The automatic sensitivity algorithm has been switched on so that it maintains a margin of twice the sensitivity threshold, adapted continuously over time.

5 : Ventricular lead
Similarly, the automatic adjustment algorithm of the pacing threshold has been activated so that the pacing amplitude is periodically adapted based on repetitive measurements of the pacing threshold. Results are excellent since the PM provides the minimal pacing amplitude that can be programmed with a margin of 100% compared to the calculated pacing threshold (2.0V at 0.4 ms of pulse duration). The same functioninality applies to ventricular sensitivity.

6 : Episodes of fast rate
Episodes of atrial and ventricular arrhythmia are continuously recorded and stored in the PM memory.

Case 2b

EGM tracing

7 : Real-time EGM recording; atrial activity is sensed and followed by a ventricular stimulation at the end of the atrial-sensed AV delay.

8 : Premature Ventricular Complexes correctly sensed (VS); we can see on the EGM that the atrial activity has not been seen by the PM since it is included within the Post-Ventricular Atrial Blanking period.

Initial Interrogation Report

Pacemaker Model: Medtronic Adapta ADDR01 Serial Number: Date of Visit:

Patient Name: **ID:** **Physician:**

Permanent Parameters

Modes

Mode	AAI<=>DDD
Mode Switch	On
Detection Rate	175 bpm
Detection Duration	No Delay
Blanked Flutter Search	On

①

Rates

Lower Rate	60 ppm
Upper Tracking Rate	130 ppm
Upper Sensor Rate	130 ppm
ADL Rate	95 ppm

Intrinsic/AV

Paced AV	150 ms
Sensed AV	120 ms
Search AV+	Off
Rate Adaptive AV	Off

Refractory/Blanking

PVARP	Auto
Minimum PVARP	250 ms
PVAB	180 ms
Ventricular Refractory	230 ms
Vent. Blanking (after A. Pace)	28 ms
PMT Intervention	On
PVC Response	On
Ventricular Safety Pacing	On

②

Rate Response

Optimization	On
ADL Response	3
Exertion Response	3
ADLR Percent	2.0%
Activity Threshold	Medium/Low
Activity Acceleration	30 sec
Activity Deceleration	Exercise
High Rate Percent	0.2%
ADL Rate Setpoint	11
Upper Sensor Rate Setpoint	33

③

Atrial Lead

Amplitude	1.500 V
Pulse Width	0.40 ms
Sensitivity	0.50 mV
Sensing Assurance	On
Pace Polarity	Bipolar
Sense Polarity	Bipolar
Lead Monitor	Monitor Only
Maximum Impedance	4,000 ohms
Minimum Impedance	200 ohms
Monitor Sensitivity	8
Capture Management	Adaptive
Amplitude Margin	2x

④

Atrial Lead

Min. Adapted Amplitude	1.500 V
Capture Test Frequency	Day at ...
Capture Test Time	1:00 AM
Acute Phase	Off
Acute Phase Complete	06/12/11

Ventricular Lead

Amplitude	2.000 V
Pulse Width	0.46 ms
Sensitivity	2.80 mV
Sensing Assurance	On
Pace Polarity	Bipolar
Sense Polarity	Bipolar
Lead Monitor	Monitor Only
Maximum Impedance	4,000 ohms
Minimum Impedance	200 ohms
Monitor Sensitivity	8
Capture Management	Adaptive
Amplitude Margin	2x
Min. Adapted Amplitude	2.000 V
Capture Test Frequency	Day at Rest
Acute Phase	Off
Acute Phase Complete	06/12/11
V. Sensing During Search	Adaptive

⑤

Additional/Interventions

RDR Detection Type	Off
Sleep	Off
Non-Comp. Atrial Pacing	On
Transtelephonic Monitor	Off
Extended Telemetry	Off
Extended Marker	Standard
Implant Detection	Off/Complete
Conducted AF Response	Off
Post Mode Switch Pacing	Off
Atrial Preference Pacing	Off

Atrial High Rate Episodes

Episode Trigger	Mode Switch
Detection Rate	175 bpm
Detection Duration	No Delay
Collection Delay	30 sec
Episode Collection Method	Rolling

Ventricular High Rate Episodes

Detection Rate	180 ppm
Detection Beats	5 beats
Termination Beats	5 beats
SVT Filter	On
Episode Collection Method	Rolling

⑥

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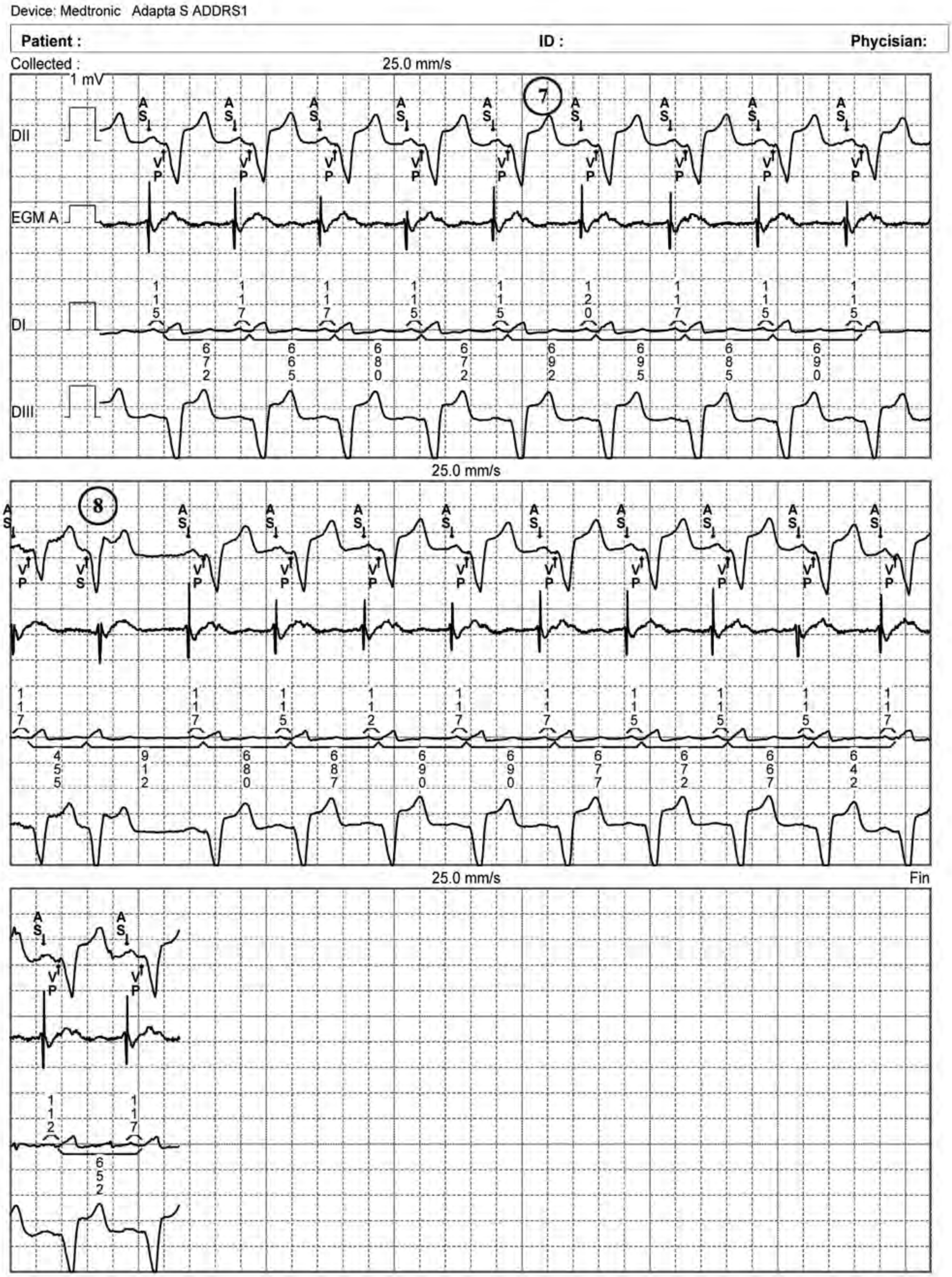
 Page 3


Device: Medtronic Adapta S ADDRS1
Patient :
ID :
Phycisian:
Collected :
25.0 mm/s
1 mV
DII
EGM A
DI
DIII
7
8
25.0 mm/s
25.0 mm/s
Fin

Characteristics of the atrial pacing lead

Pacing lead assessment is an important step of the standard PM evaluation, including the pacing threshold, the sensing threshold and lead impedance measurements.

Case 3a

1 : Atrial impedance time-curve

This parameter is a good marker of the lead integrity; a low value is often associated with loss of insulation integrity whereas a high value suggests a problem with the conductor coil. It is important to consider not only the absolute value of the impedance, but also variations over time including abnormal values. The impedance variations curve is a precious tool to explore trends in the mid- and long-term follow-up. In this patient, impedance values are stable and normal (around 450 ohms) ; no abnormal (too low or too high) values have been observed.

Case 3b

2 : Atrial pacing threshold testing

In this PM-dependent patient, the atrial pacing threshold test has been achieved in DDD mode. Here, the threshold reaches 0.5 V which appears to be very low; the loss of atrial capture can be easily observed on the tracing since it is associated with the recurrence of spontaneous atrial rhythm (AR).

Case 3c

3 : Atrial sensitivity time-curve

Atrial sensitivity is programmed to 0.5 mV since the PM implant.

Case 3d

4 : P-wave measurements time-changes

Those measurements are automatically achieved. In this case, they are stable and above 2 mV which allows a comfortable margin over the programmed sensitivity.

Case 3e

5 : Real-time measurement of the P-wave amplitude

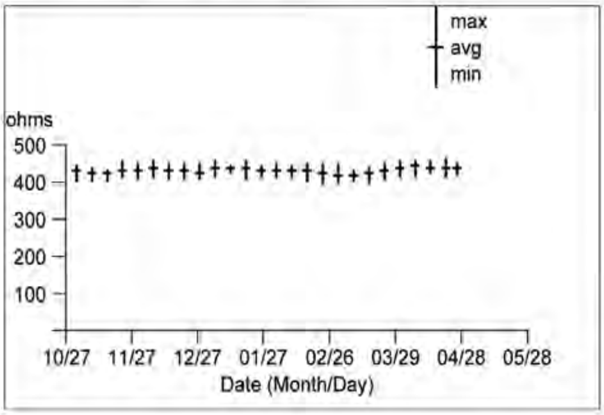
Manually, the P-wave amplitude fluctuates with a value of between 2.8 and 4 mV which corresponds to the values automatically calculated by the PM.

Atrial Impedance Trend - Chronic Report

Pacemaker Model: Medtronic Adapta ADDR01 Serial Number: Date of Visit:

Patient Name:	**ID:**	**Physician:**

Data Collection Period: 02/27/12 - 04/20/13



Initial Interrogation

Pace Polarity	Bipolar
Sense Polarity	Bipolar
Lead Monitor	Monitor Only
Lead Trend	On

(1)

Measured Impedances

Initial	339 ohms
At Interrogation	441 ohms
Lifetime Min	269 ohms
Lifetime Max	477 ohms

Notable Data

High Impedance	0
Low Impedance	0

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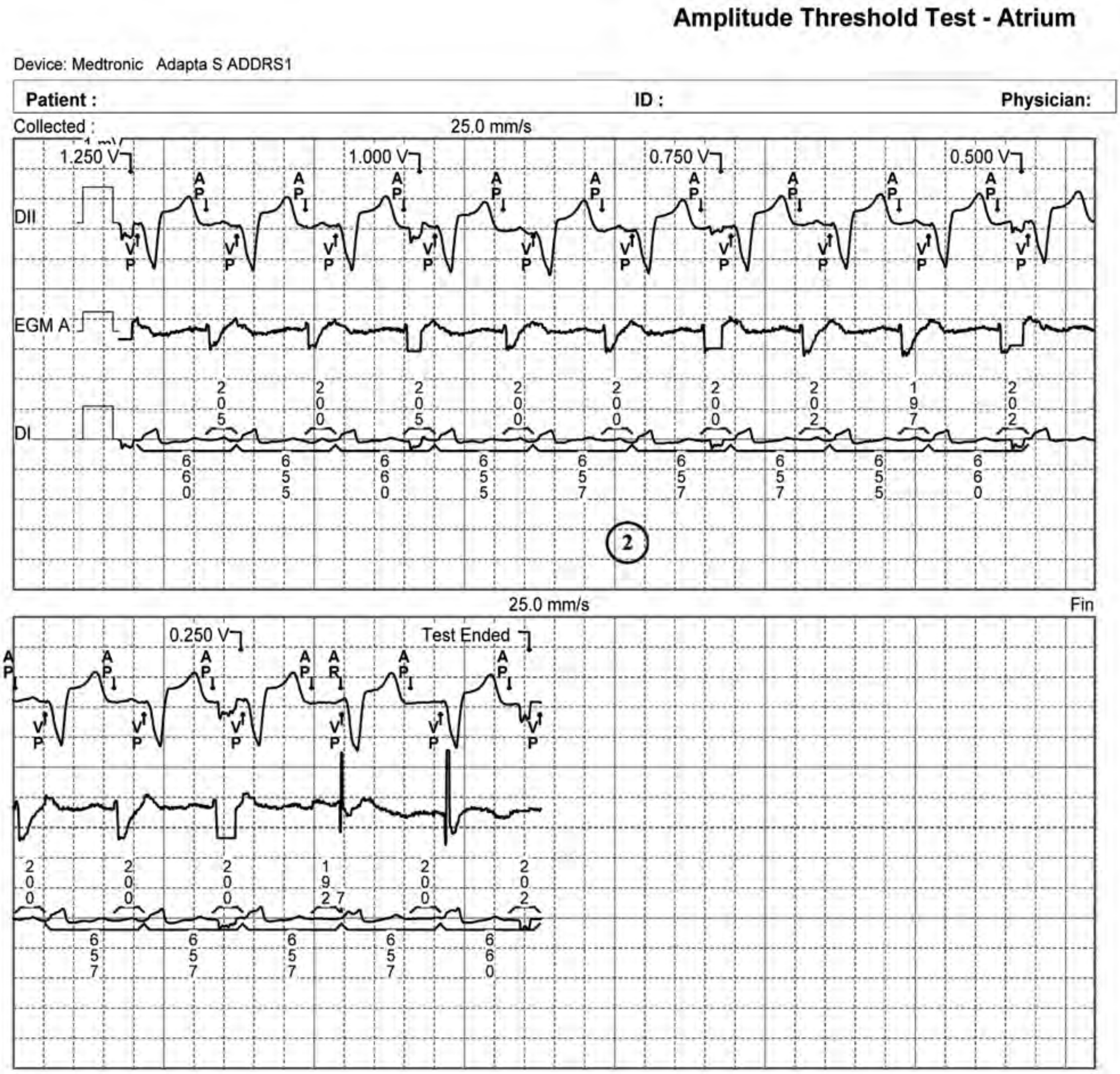
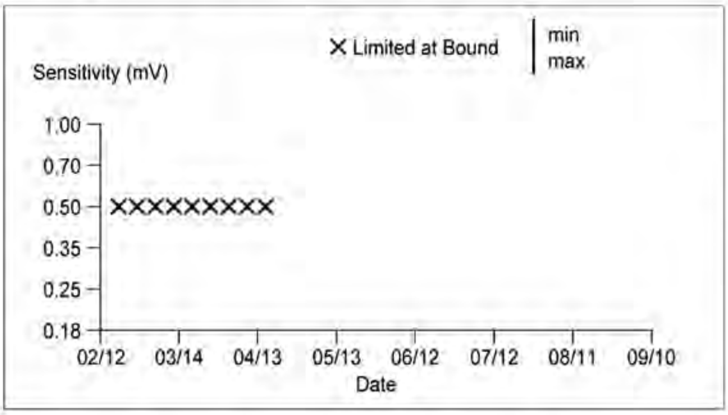

Amplitude Threshold Test - Atrium
Device: Medtronic Adapta S ADDRS1
Patient :
ID :
Physician:
Collected :
25.0 mm/s
1.250 V
1.000 V
0.750 V
0.500 V
DII
EGM A
DI
25.0 mm/s
Fin
0.250 V
Test Ended

Auto Sensitivity Trend Report

Pacemaker Model: Medtronic Adapta ADDR01 Serial Number: Date of Visit:

Patient Name:	ID:	Physician:

Sensitivity - Atrial 02/12/13 4:02 PM - 04/20/13 8:11 AM



Initial Interrogation

Mode	DDD
Sensitivity	0.50 mV
Sense Polarity	Bipolar
Lead Monitor	Monitor Only

Notable Data

Sampled every 7 days

(3)

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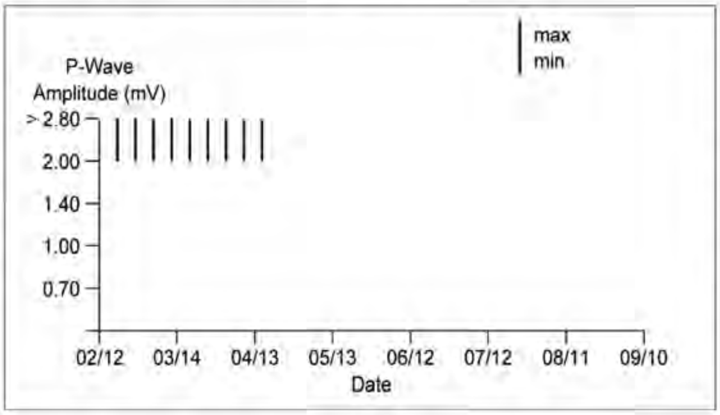
Auto Sensitivity Trend Report

Pacemaker Model: Medtronic Adapta S ADDRS1 Serial Number: Date of Visit:

Patient Name:	ID:	Physician:

P-Wave Amplitude 02/12/13 4:02 PM - 04/20/13 8:11 AM



Initial Interrogation

Mode	DDD
Sensitivity	0.50 mV
Sense Polarity	Bipolar
Lead Monitor	Monitor Only

Notable Data

Sampled every 7 days

Current Sample

Min. P-Wave Amplitude 2.0 mV
Max. P-Wave Amplitude >2.8 mV
Min. Safety Margin 4.0X

(4)

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04/21/13 8:58:17 PM
Page 1

□□□□ □□□□□□□R□port

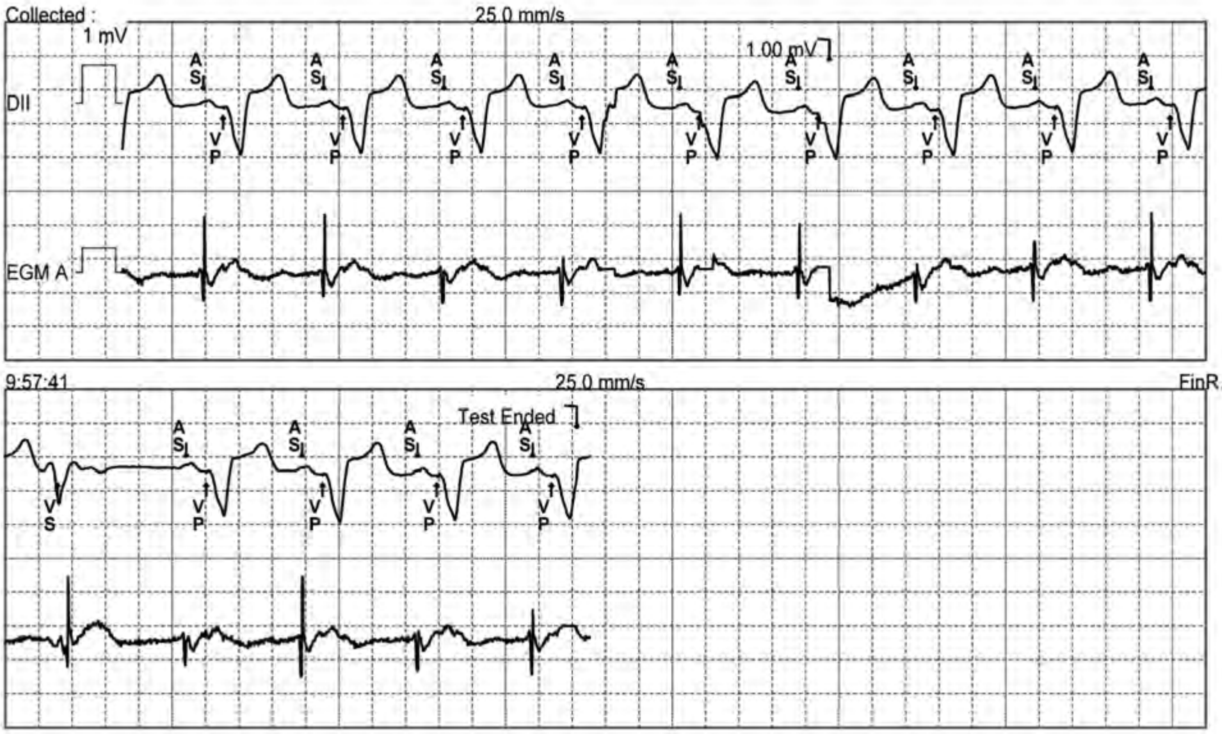
Device : Medtronic Adapta S ADDRS1

□□□□□:	ID :	□□□□□□□ :

□□□□□□□□ □□□□□

Test Value	
Temp. Mode	DDD
Temp. Lower rate	30 min-¹
Temp. Sensed AV	120 ms
Temp. Atrial Sensivity	1.00 mV

Measured P Wave Amplitude Between : 2.80 - 4.00 mV



5

Medtronic Logiciel SW003 7.3

Characteristics of the ventricular pacing lead

Case 4a

1 : Ventricular impedance trends

In this patient, impedance values are stable and normal (around 600 ohms) ; no abnormal (too low or too high) value has been observed

Case 4b

2 : Variations of the ventricular pacing threshold measurements and automatic assessment by the PM

The ventricular pacing thresholds are stable and below 1.0V at 0.4ms pulse duration, which permits programming the ventricular voltage output to 2.0V at 0.4ms. This ensures an adequate pacing safety margin and avoids battery wasting.

Case 4c

3 : Real-time ventricular pacing threshold in VVI mode (70ppm)

The pacing threshold is measured at 0.5V, without underlying spontaneous rhythm. Since the patient is PM-dependent, the ventricular pause that would occur at the loss of ventricular capture (at the end of the pacing threshold test) might be poorly tolerated by the patient, so that the number of non-capture beats (during the pacing threshold testing) should be kept minimal (one or two paced beats).

Case 4d

4 : Real-time ventricular pacing threshold in DDD mode (70ppm)

The pacing threshold is also measured at 0.5V and corresponds to the value automatically calculated by the PM.

Case 4e

5 : Trends of the programmed ventricular sensitivity

Ventricular sensitivity is programmed at 2.8mV since the PM implant.

Case 4f

6 : Real-time R-wave amplitude measurements

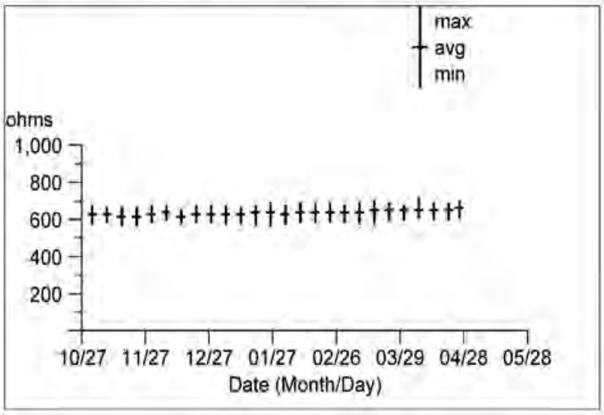
The ECG illustrates complete atrioventricular block with an escape rhythm of 45 bpm. The sensitivity test has been achieved based on this underlying rhythm with an R-wave measured between 8 and 11.2mV.

Ventricular Impedance Trend - Chronic Report

Pacemaker Model: Medtronic Adapta ADDR01 Serial Number: Date of Visit:

Patient Name: **ID:** **Physician:**

Data Collection Period: 02/27/12 - 04/20/13



Initial Interrogation

Pace Polarity	Bipolar
Sense Polarity	Bipolar
Lead Monitor	Monitor Only
Lead Trend	On

Measured Impedances

Initial	540 ohms
At Interrogation	711 ohms
Lifetime Min	376 ohms
Lifetime Max	713 ohms

(1)

Notable Data

High Impedance	0
Low Impedance	0

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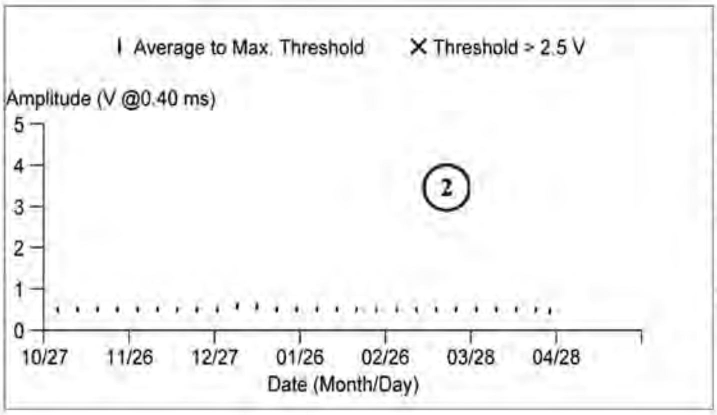
 Page 1

Ventricular Capture Management Trend Report

Pacemaker Model: Medtronic Adapta ADDR01 Serial Number: Date of Visit:

Patient Name:	ID:	Physician:

Data Collection Period: 02/27/12 - 04/20/13



Initial Interrogation

Capture Management	Adaptive
Capture Test Frequency	Day at Rest
V. Amplitude	2.000 V
V. Pulse Width	0.46 ms
Amplitude Margin	2x
V. Min. Adapted Amplitude	2.000 V
Acute Phase Complete	06/12/11

Measured Threshold

04/19/13 10:46 PM
0.375 V at 0.40 ms

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04/20/13 10:34:48 AM
Page 1

Automatic Amplitude Threshold Test

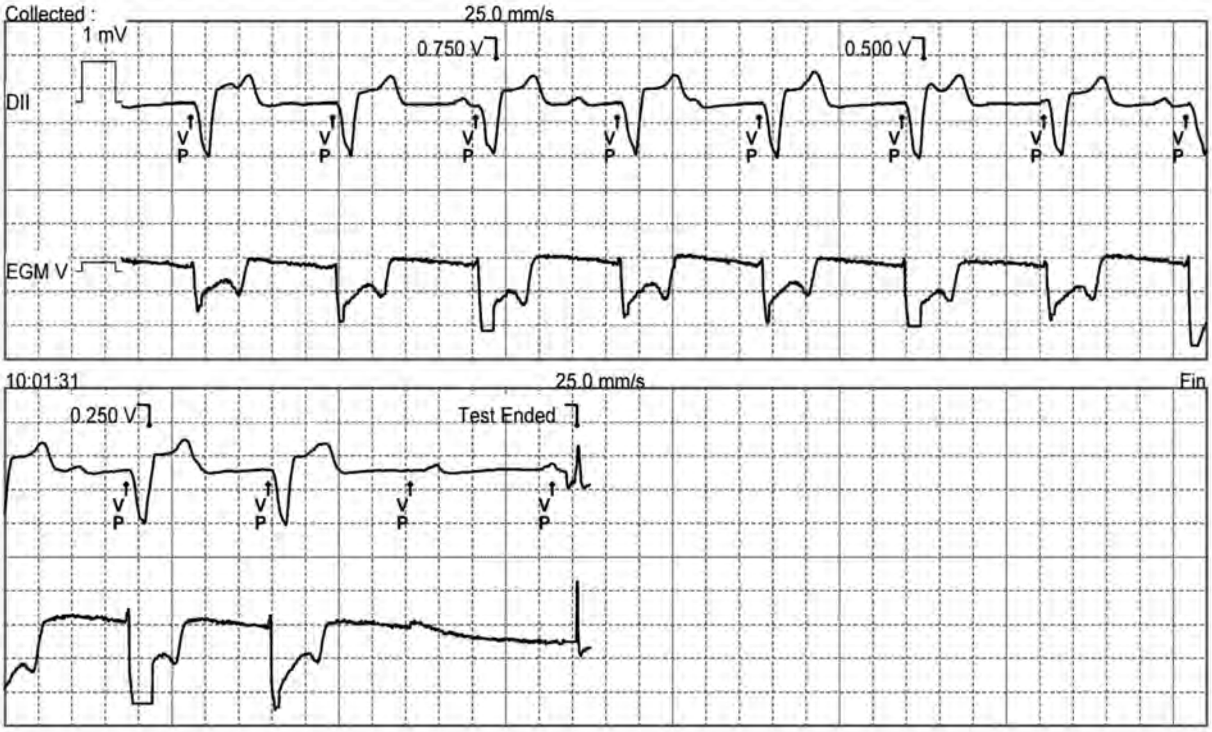
Device : Medtronic Adapta S ADDRS1

Patient : **ID :** **Physician :**

Automatic Ventricular Amplitude

	Test Value	Threshold
Mode	VVI	
Lower Rate	70 min-¹	
V. Amplitude	0.250 V	0.250 V
V. Pulse With	0.46 ms	

(3)



Medtronic Logiciel SW003 7.3

Device : Medtronic Adapta S ADDRS1

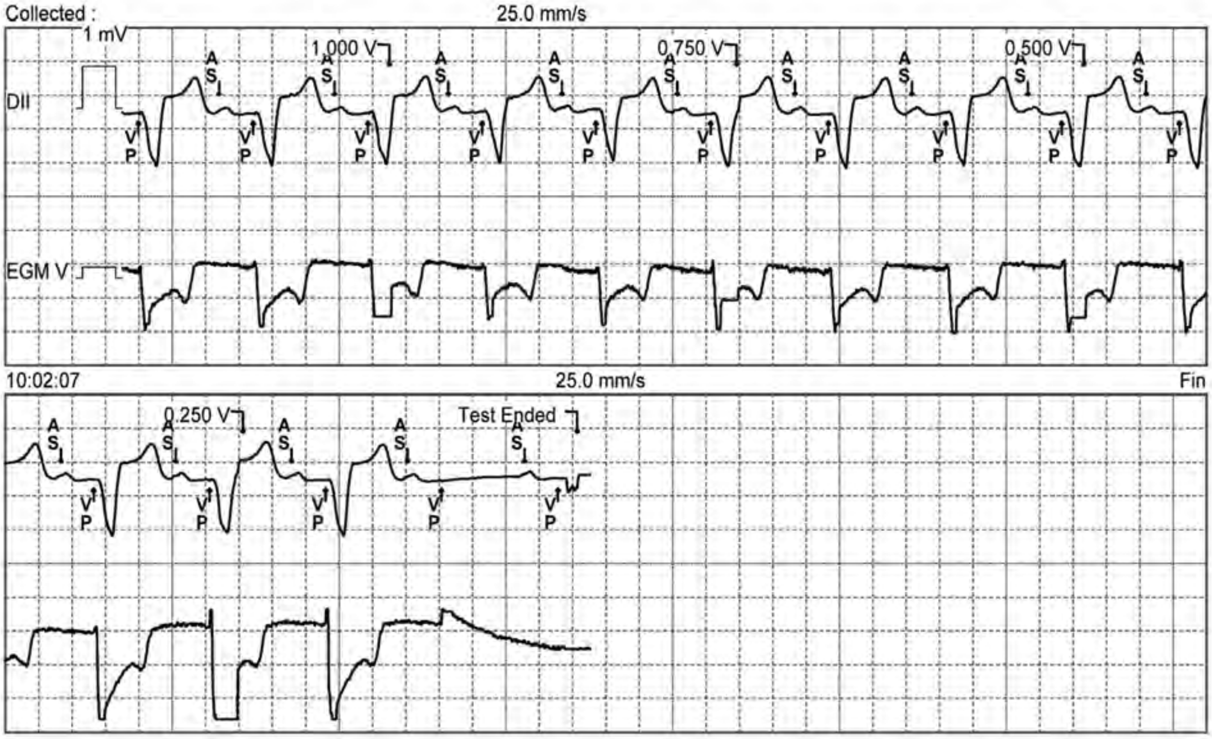
Patient :	ID :	Physician :

Ventricular Threshold

	Val	
Mode	DDD	
Lower Rate	70 min-¹	
Paced AV Delay	200 ms	
V Amplitude	0.250 V	0.250 V
V Pulse Width	0.46 ms	

(4)

Collected : 25.0 mm/s



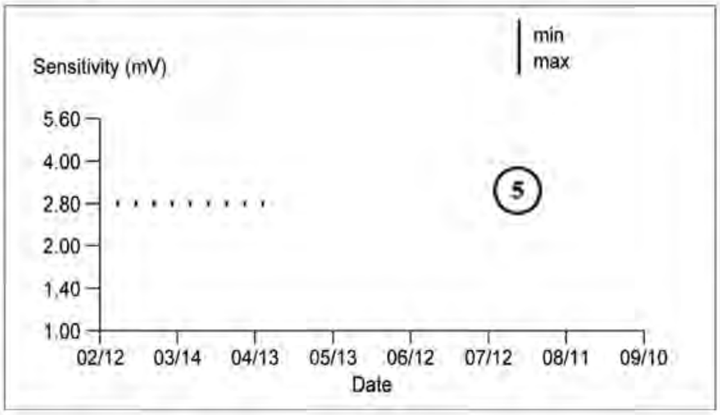
Medtronic Logiciel SW003 7.3

Auto Sensitivity Trend Report

Pacemaker Model: Medtronic Adapta S ADDRS1 Serial Number: Date of Visit:

Patient Name:	ID:	Physician:

Sensitivity - Ventricular 02/12/13 4:02 PM - 04/20/13 8:11 AM



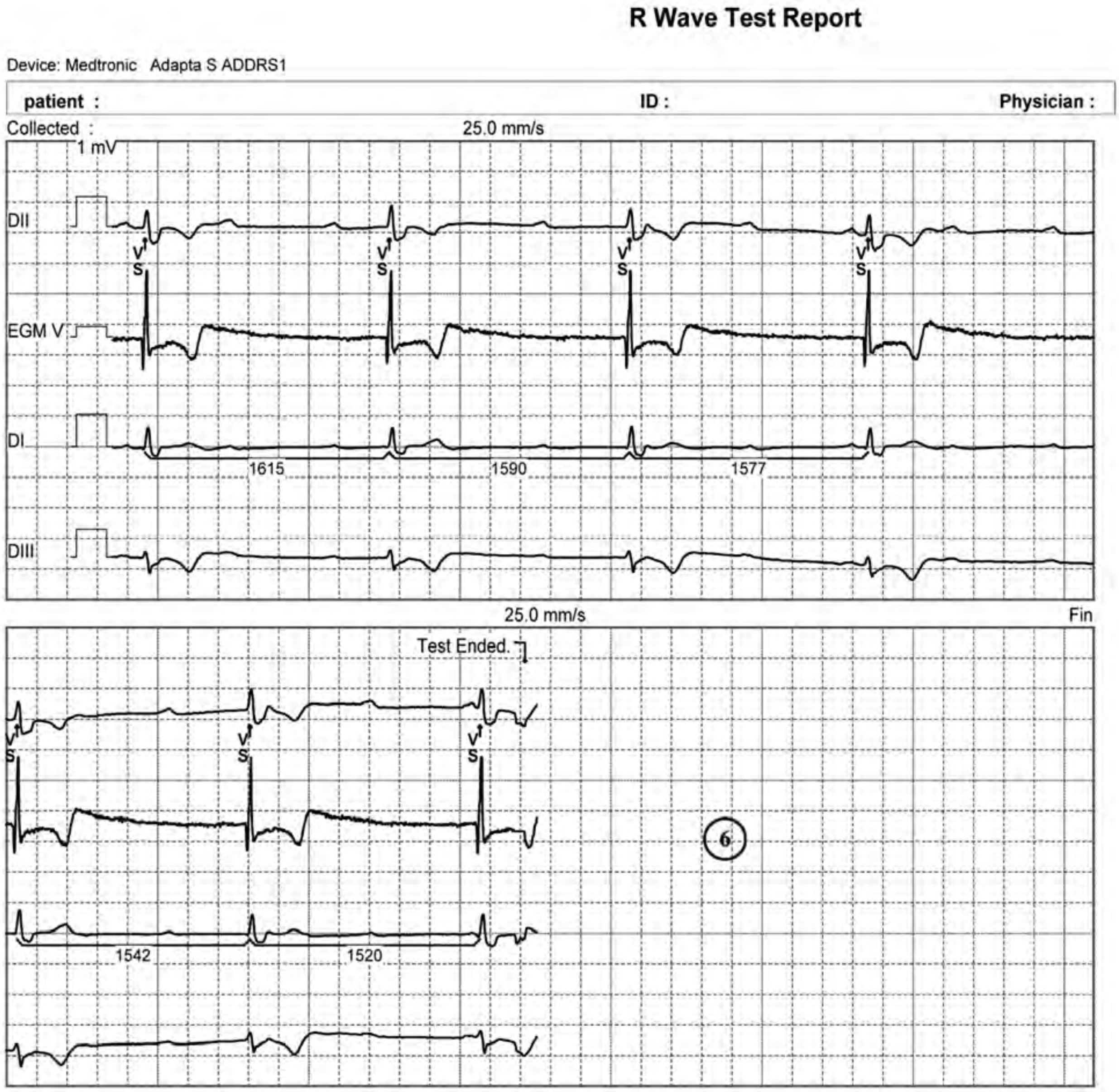
Initial Interrogation

Mode	DDD
Sensitivity	2.80 mV
Sense Polarity	Bipolar
Lead Monitor	Monitor Only

Notable Data

Sampled every 7 days

Medtronic Software SW003 7.3 04/21/13 8:58:32 PM
 Page 1


R Wave Test Report
Device: Medtronic Adapta S ADDRS1
patient :
ID :
Physician :
Collected :
25.0 mm/s
1 mV
DII
EGM V
DI
DIII
VS
1615
1590
1577
25.0 mm/s
Fin
Test Ended.
1542
1520
6

Pacing Modes

Pacing Modes

Depending on the number of leads and device model implanted, various pacing modes are available. The functions, advantages and disadvantages associated with each pacing mode must be familiar to the caregivers in charge of the follow-up, in order to optimize the programming, taking into consideration the specific characteristics of the various device recipients.

The international code

The combined efforts by the North American (NASPE) and British (BPEG) societies of pacing and electrophysiology have defined the international code (NBG) for the classification of the various pacing modes. The pacing modes are assigned a 4- or 5-letter code that describes their primary function.
The first letter defines the ventricular (V), atrial (A), both (D), single chamber (S) or no (0) pacing site(s);
The second letter defines the sensing site(s) using the same letters;
The third letter defines the pacing mode, inhibited (I), triggered (T), both (D), or none of these (0);
The fourth letter indicates the presence (R) or absence (0) or rate responsiveness;
The fifth letter defines atrial (A), ventricular (V) or dual (D: A+V) multisite stimulation, if present, and (0) if absent;

Single chamber pacemakers

The asynchronous modes SOO (VOO and AOO)

- Single chamber pacing
- No sensing
- Asynchronous pacing

The A00 and V00 modes pace asynchronously at a fixed programmed rate, without inhibition by spontaneous events in the paced cavity. The only interval that needs to be programmed is the pacing interval (or the rate = 60,000/pacing interval). It is the most primitive pacing mode, the only mode available in the very first programmable pacemakers.
Electrocardiographic characteristics of V00 mode: regular ventricular stimuli without interference by the intrinsic activity.
Electrocardiographic characteristics of A00 mode: regular atrial stimuli without interference by the intrinsic activity.
A00 and V00 are the respective magnet modes of the corresponding single chamber atrial and ventricular pacing modes. The V00 mode is also the magnet mode of the VDD mode.
The programming of S00 is obsolete as permanent modes, and it is now limited to test modes. They were initially programmed to prevent the sensing of, and inhibition by, electromagnetic interferences in pacemaker-dependent patients. However, this pacing mode is associated with a risk of arrhythmogenesis by delivery of pacing pulses on the T wave.

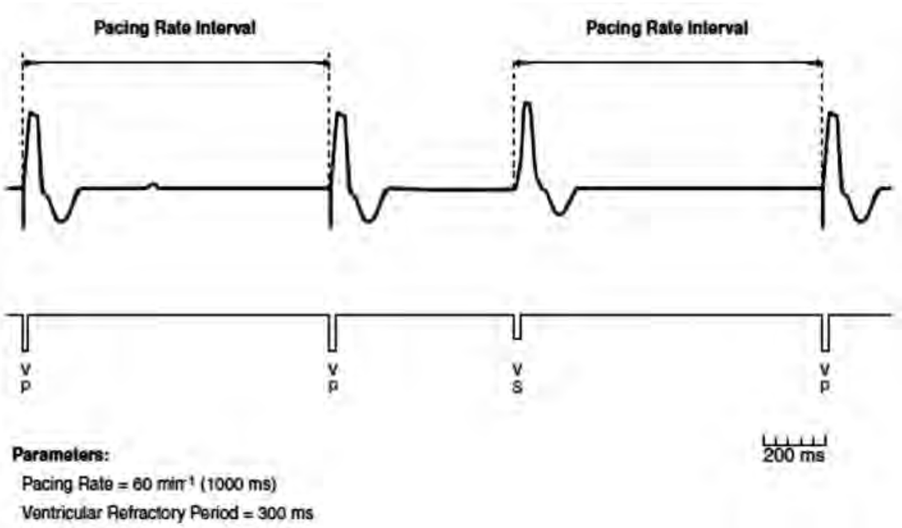
The SSI/SSIR modes

SSI is a single chamber mode, that is VVI if the lead is implanted in the ventricle and AAI if the lead is in the atrium. In both VVI and AAI, a pacing pulse is delivered at the end of a programmable escape interval. If a spontaneous event is sensed, pacing is inhibited and an escape interval is reset. In absence of spontaneous event, the device paces at the end of a programmed interval.

The VVI/VVIR mode

- Ventricular pacing
- Ventricular sensing
- Inhibition by the sensing of a ventricular signal outside the refractory periods

The VVI mode paces a single chamber at the programmed pacing rate, unless inhibited by a sensed event. Sensing is limited to the ventricle. An escape interval is initiated after all ventricular sensing.
It is noteworthy that the spontaneous sensing of a ventricular signal by the pacemaker can be delayed with respect to the onset of the QRS complex on the surface ECG. This is particularly apparent in presence of right bundle branch block, as the QRS is sensed when the ventricular depolarization wavefront passes by the cathode in the right ventricle.
The first component of the RR cycle, whether after sensing or after pacing, is the refractory period, during which the pacemaker cannot react to a sensed signal. A signal occurring during this refractory period does not reset the escape interval. This refractory period is needed to prevent double sensing of a same spontaneous or paced QRS complex. A signal sensed after the refractory period inhibits pacing and resets the escape interval.
Typical electrocardiographic findings: ventricular pacing (wide QRS) with inhibition of pacing by spontaneous QRS complex.



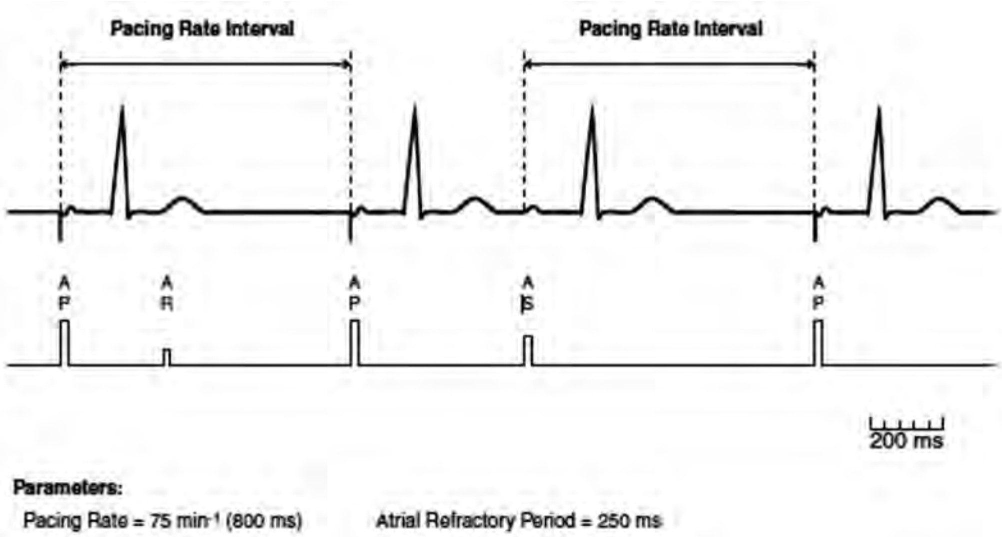
The VVIR mode paces a single ventricular chamber in a rate responsive manner, i.e. varies the pacing rate according to activity, tracked by a sensor.

The VVI/VVIR mode is particularly indicated for patients with chronotropic incompetence in permanent atrial fibrillation, for whom atrial sensing and pacing are useless. It can also be programmed in patients who present with episodes of paroxysmal bradycardia. The back up rate is programmed below the spontaneous rate of the patient and the pacemaker intervenes only when pauses occur.

AAI/AAIR mode

- Atrial pacing
- Atrial sensing
- Inhibited by sensing of atrial signals outside the refractory period.

AAI is a single chamber atrial pacing mode at the programmed rate unless inhibited by a sensed event. Sensing is limited to the atrium.
The programming and functions of the device are nearly the same as for a VVI pacemaker. However, the programming of sensitivity must be higher (lower programmed values), as the amplitude of atrial complexes is often lower than that of ventricular complexes. Furthermore, the refractory period must be longer, to eliminate all ventricular oversensing. The sensing of an R wave by an AAI pacemaker slows the pacing rate, because each sensed R wave resets the escape interval. In the presence of crosstalk (sensing of the R wave), the pacemaker can be programmed to a less sensitive value or the refractory period can be lengthened.
Typical electrocardiographic observations: atrial pacing inhibited by sensing of spontaneous atrial activity.



AAIR is a rate responsive, single chamber, atrial pacing mode.
The preferred indication for an AAI/AAIR pacemaker is the presence of pure sinus node dysfunction with preservation of normal AV conduction. It is, therefore, important, at the time of implantation, to verify the preservation of normal AV conduction. The presence of 1:1 AV conduction beyond a pacing rate of 120 bpm associated with a normal PR interval and normal QRS suggests that conduction is preserved, in which case the risk of AV block is <1% per year.

The SST (VVT or AAT) modes

- Ventricular or atrial pacing
- Ventricular or atrial sensing
- Pacing triggered by R or P wave sensed outside the refractory period

In AAT and VVT modes, the programmed paced rate is the slowest rate seen; however an event sensed outside the refractory periods triggers an immediate paced event in the corresponding chamber. This mode is safe, as pacing occurs systematically in the natural, absolute refractory period of the ventricular or atrial myocardium. The 3 important programmable parameters are the back-up rate, the maximum pacing rate and the refractory period. The last 2 prevent the running away of the pacemaker in case of sensing of rapid signals.
Typical electrocardiographic observations in VVT: in the absence of intrinsic cardiac activity, the

ventricles are paced at a fixed cycle length. The occurrence of a spontaneous ventricular complex outside the refractory periods triggers a pacing stimulus inside the QRS. The QRS is either identical to the spontaneous QRS (pseudo-fusion) or intermediate between the spontaneous and the paced QRS (fusion).
Typical electrocardiographic observations in AAT: same as the ventricle but in the atrium.

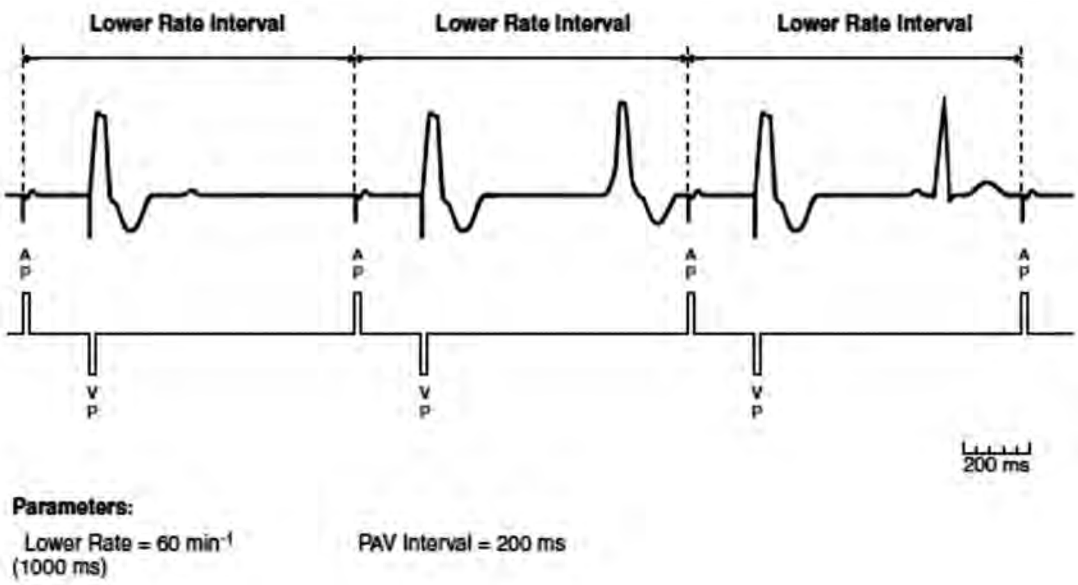
These pacing modes are rarely used today. Pacing triggered by sensing is a useless waste of energy and acceleration of the battery drain. These modes can be used temporarily to prevent pacing inhibition in a pacemaker-dependent patient presenting with oversensing. They also allow the verification of the quality and timing of sensing when assessing device function.

Dual chamber pacemakers

The D00 mode

- Asynchronous dual chamber pacing
- No sensing

The D00 mode paces AV sequentially at the programmed back-up rate without inhibition by intrinsic events.
The AV and VA delays are fixed and are not reset, as sensing does not exist.
Typical electrocardiographic observations: regular atrial pacing followed by ventricular pacing without interference by the intrinsic atrial or ventricular activity.



D00 is a programmable mode but D00 is also the mode seen when a magnet is placed over the pacemaker, except for the VDD mode (V00 magnet mode, as atrial pacing is nonexistent).

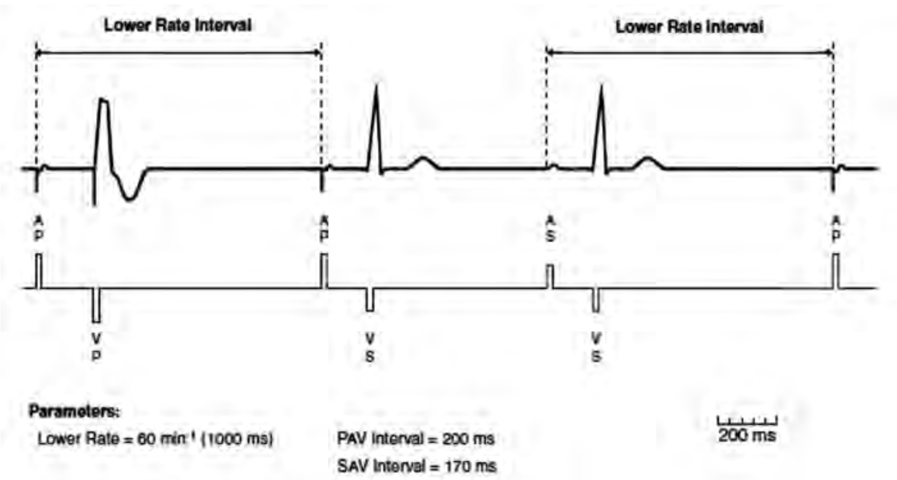
DDD/DDDR mode

- Dual (atrial and ventricular) pacing
- Dual (atrial and ventricular) sensing
- Dual response (inhibited and triggered) to sensing

DDD is the standard programming of dual chamber pacemakers or resynchronization devices. It ensures AV synchronization at rest as well as during exercise during sensed or paced atrial rhythms. Spontaneous atrial activity occurring outside the refractory periods inhibits atrial pacing. Spontaneous ventricular activity outside the refractory periods inhibits ventricular pacing.
Each paced or sensed atrial event outside the refractory periods starts an AV delay and the programmed pacing rate.

The AV delays which follow sensed and paced atrial events are programmable independently; a shortening of the AV delay can be programmed when the rate increases (rate-adaptive AV delay) or can be modified according to the spontaneous conduction intervals (AV delay + hysteresis).
A paced ventricular event might follow a sensed atrial event up to the programmed synchronous upper rate or maximum tracking rate: the limit at which the pacemaker is no longer allowed to pace the ventricle in synchrony with the atrial rate.

Typical electrocardiographic observations: the tracings may show spontaneous and paced atrial events as well as spontaneous and paced ventricular events. A paced ventricular event could be synchronous with either an intrinsic or a paced atrial event. Schematically, both chambers might be paced, accounting, however, for the spontaneous activity that inhibits pacing in that cavity.

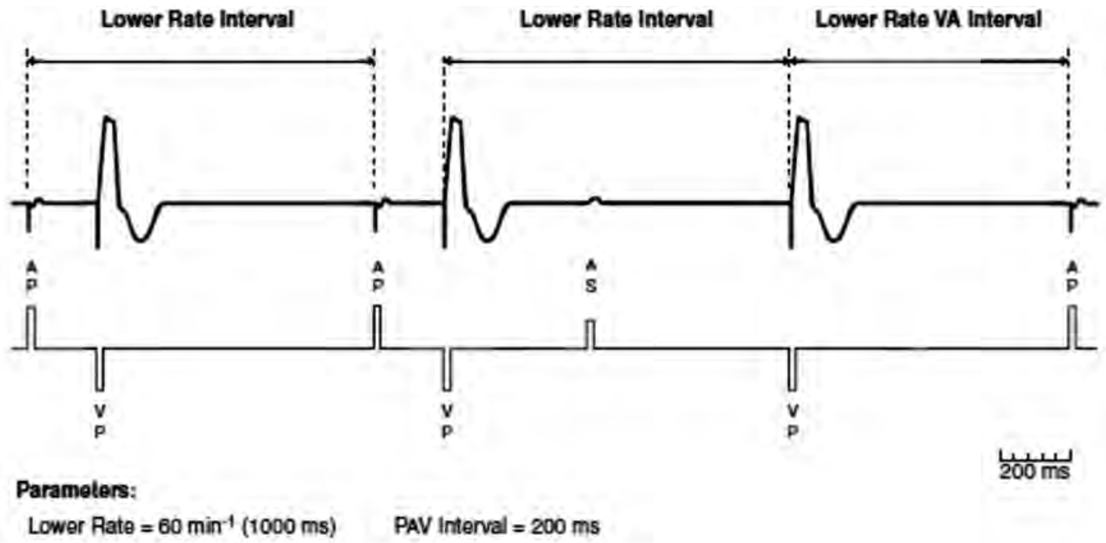


In DDDR mode, the pacemaker follows the fastest rate, whether spontaneous atrial or sensor-driven. The maximum tracking rate and the maximum sensor-driven rate are independently programmable. The DDDR mode is expected to fit the needs of all pacemaker recipients.

DDI/DDIR mode

- Dual pacing (atrial and ventricular)
- Dual sensing (atrial and ventricular)
- Inhibition by sensed events (atrial and ventricular)

The atria are paced at the slowest programmed rate.
After atrial pacing, the ventricle is paced at the end of the AV delay if no ventricular event is sensed during this delay.
An atrial event sensed outside the refractory periods inhibits atrial pacing and never triggers an AV delay.
Thus, after atrial sensing and in absence of spontaneous AV conduction, the ventricle is paced at the back-up rate, dissociated from atrial sensing, as in the case of a VVI pacemaker.
The typical appearance hinges on the absence of P-synchronous ventricular pacing. AV synchronization is ensured only when the atrium is paced.
In case of an atrial arrhythmia, rapid ventricular pacing never occurs since a spontaneous atrial event never triggers an AV delay.



The DDI mode may be indicated in the case of frequent atrial arrhythmias in a patient presenting with bradycardia-tachycardia syndrome.

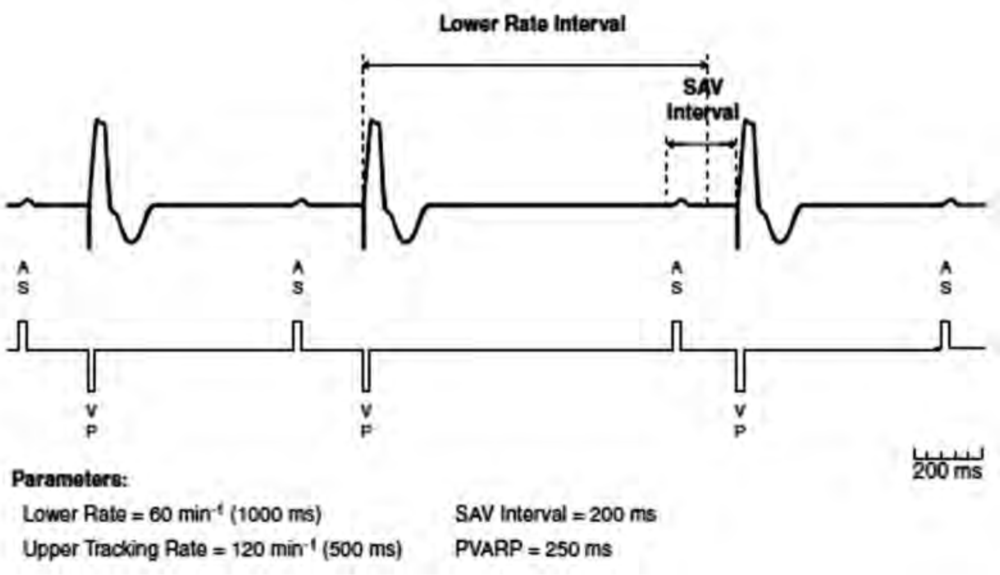
This pacing mode is not suitable for patients who present with complete AV block and a rapid spontaneous atrial rate, as the spontaneous P waves do not initiate a synchronous AV delay. This pacing mode can be programmed in patients presenting with complete AV block and sick sinus syndrome: if sinus node dysfunction is present, AV pacing will occur; during an arrhythmic episode, the rapid spontaneous atrial activity is not followed by rapid ventricular pacing. This mode is particularly useful when the fallback or mode-switching algorithm fails.

VDD mode

- Ventricular pacing
- Dual sensing (atrial and ventricular)
- Ventricular pacing triggered by atrial sensing, inhibited by atrial and ventricular events.

Sensing occurs in the atrium and in the ventricle, while pacing is limited to the ventricle. In VDD, pacing is synchronized to atrial sensing. In the absence of atrial activity, effective VVI pacing is seen. The ventricle is paced synchronously to the atrium up to the programed upper rate limit.

Typical electrocardiographic manifestations: the atrium is never paced; therefore, if sinus pauses or arrest occurs, ventricular pacing becomes uncoupled from the atrium (pseudo-VVI).



Therefore, since the atrium cannot be paced, the VDD mode is not suitable for patients who present with sinus node dysfunction; it is, however, appropriate for patients who suffer from complete AV block, in presence of normal sinus node and chronotropic function. It is also possible to implant a specific VDD stimulation system using a single pacing/sensing ventricular lead with two floating electrodes that sense the atrium.

DDT mode

- Identical to DDD, used as a temporary test mode.
- Offers in addition ventricular and atrial pacing in response to the sensing of all ventricular or atrial events that occur outside the refractory periods.

AAI<=>DDD or MVP mode

- Atrial pacing with rescue ventricular pacing
- Atrial and ventricular sensing
- In case of loss of AV conduction, switch to DDD mode
- If AV conduction returns, the device returns to AAI mode (it is in fact an ADI mode)

The MVP mode, AAI<=>DDD, enables AAI pacing while monitoring AV conduction. In case of persistent loss of AV conduction, pacing switches to DDD mode. When AV conduction returns, pacing returns to AAI mode.

Preserved AV conduction: the device stays in AAI mode. During AAI pacing, the settings associated with single chamber atrial pacing are applicable. Ventricular sensing is active.

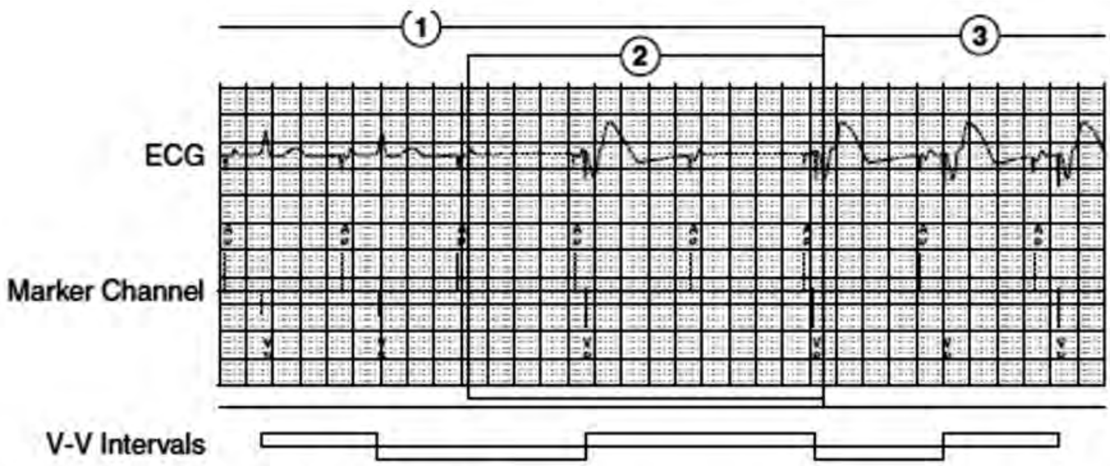
Transient loss of AV conduction: the device delivers a rescue ventricular pulse 80 ms after the AA escape interval in response to an A-A interval that is missing a sensed ventricular event.

Sustained loss of AV conduction: in absence of a ventricular event in response to 2 of the 4 of the most recent A-A intervals, the device confirms as loss of AV conduction and switches to DDD mode. It delivers ventricular safety pacing pulses in response to the missing ventricular events.

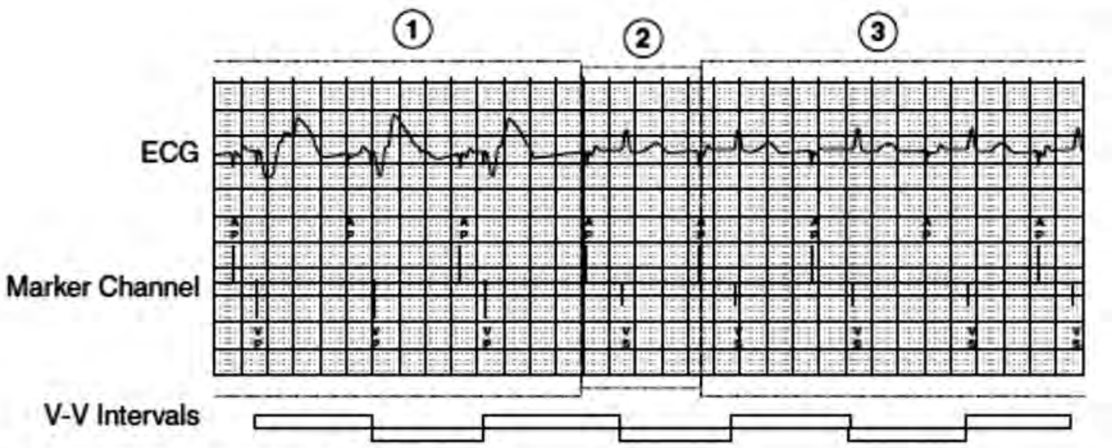
Sustained loss of AV conduction: in absence of ventricular response to 2 of the 4 latest A-A intervals, the device confirms as loss of AV conduction and switches to DDD mode.
Return of AV conduction: after switch to DDD mode, the device regularly monitors AV conduction pending the return to AAI mode. The first verification of AV conduction occurs 1 minute after switch to DDD mode. While verifying, the device switches to AAI pacing for one cycle. If the A-A interval

includes a sensed ventricular event, the monitoring of sensing was successful and the device stays in AAI mode. If the A-A interval does not include a sensed ventricular event, the monitoring of conduction has failed and the device returns to DDD mode. The interval that separates each verification of conduction doubles (2, 4, 8...minutes, up to a maximum of 16 hours).

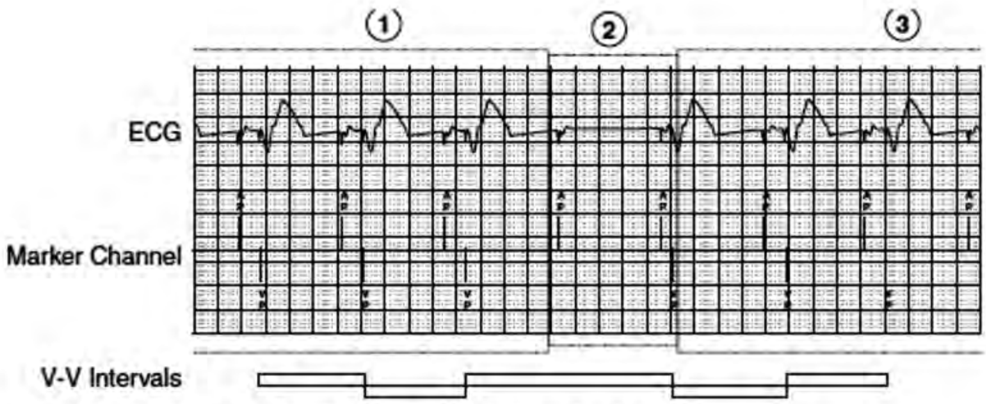
Complete AV block: the device functions persistently in DDD mode, verifying the presence of AV conduction every 16 h, resulting in a single missing cycle. All the settings associated with the DDD mode are applicable.



1 The pacemaker operates in AAIR mode.
2 At the onset of AV block, the pacemaker supplies ventricular backup paces.
3 The pacemaker switches to DDDR mode.



1 The pacemaker operates in DDDR mode.
2 The pacemaker performs an AV conduction check. AV conduction is detected.
3 The pacemaker switches to AAIR mode.



1 Remaining in DDDR mode after an AV conduction check
2 The pacemaker performs an AV conduction check. AV conduction is not detected.
3 The pacemaker continues to operate in DDDR mode.

The adverse effects of long-term right ventricular pacing have been confirmed by multiple observations. The MVP mode lowers considerably the percentage of ventricular paced events without jeopardizing the patient's safety at the onset of AV conduction abnormalities. The main indication is, therefore, the presence of sinus node dysfunction with AV conduction preserved or only intermittently abnormal.

Case 1: ODO mode

Patient

This 63-year-old man presented with a history of paroxysmal atrial fibrillation (AF) and complete right bundle branch block on the electrocardiogram (ECG). He suffered 3 episodes of syncope without prodrome. An electrophysiologic study revealed an 82-ms HV interval, prompting the implantation of an Adapta® dual chamber pacemaker. Both pacing leads were properly positioned and associated with normal impedance, and satisfactory sensing and capture thresholds. The pacemaker was interrogated 3 days after the implant and recordings were obtained during the programming of various pacing modes. This first tracing was recorded in ODO mode.

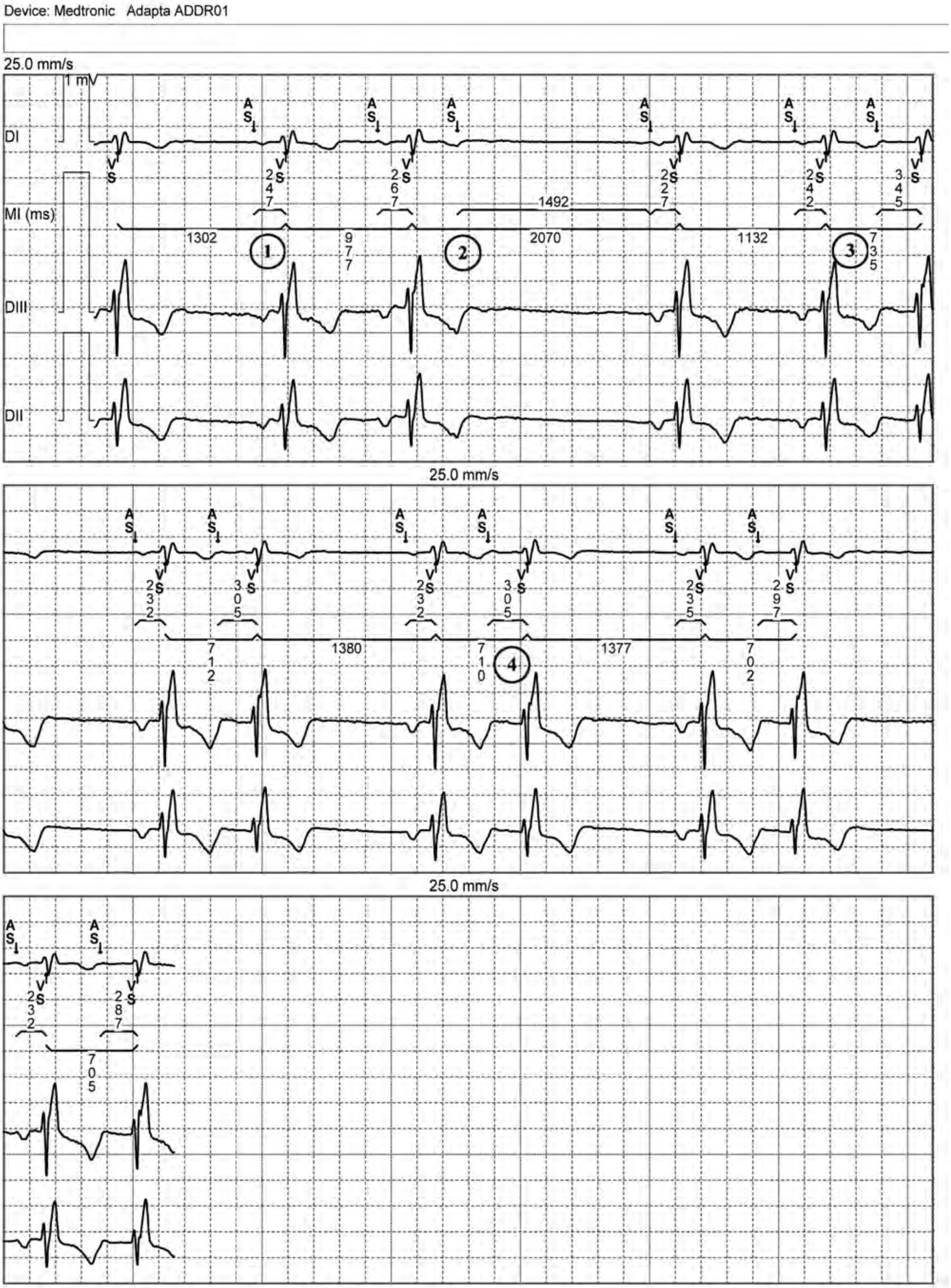
EGM

On this and the following tracings, the first channel is lead I, upon which the event markers are superimposed, the second shows the interatrial, interventricular and atrioventricular (AV) intervals, the third is lead III and the fourth channel is lead II.

1: Sinus rhythm correctly detected by the pacemaker; AS VS; wide QRS;
2: Premature atrial complex non-conducted to the ventricles;
3: Slightly later premature atrial complex conducted to the ventricles with a prolonged PR interval;
4: Atrial bigeminy;

Comments

In ODO mode, pacing is not possible; consequently, it should never be programmed in pacemaker-dependent patients; however, since sensing takes place in the chambers explored, this mode allows an analysis of the spontaneous rhythm along with a concomitant visualization of the ECG and the event markers. The blanking periods are shortened in order to favor the effective sensing periods. Therefore, the ODO mode can be used to test the sensitivity. It can be programmed temporarily in non-dependent recipients of MRI-compatible pacemakers who need to undergo MR examination. Programming of the ODO mode prevents the reversion to VVI. One must, of course, not forget to re-interrogate and reprogram the pacemaker after using any temporary pacing mode.


Device: Medtronic Adapta ADDR01
25.0 mm/s
1 mV
DI
MI (ms)
DIII
DII
AS
VS
247
267
227
242
345
1302
977
1492
2070
1132
735
1
2
3
25.0 mm/s
232
305
235
297
712
1380
710
1377
702
4
25.0 mm/s
232
287
705

Case 2: Asynchronous modes

Patient

Same patient as in Case 1.

EGM

DOO mode programmed at 40 bpm;

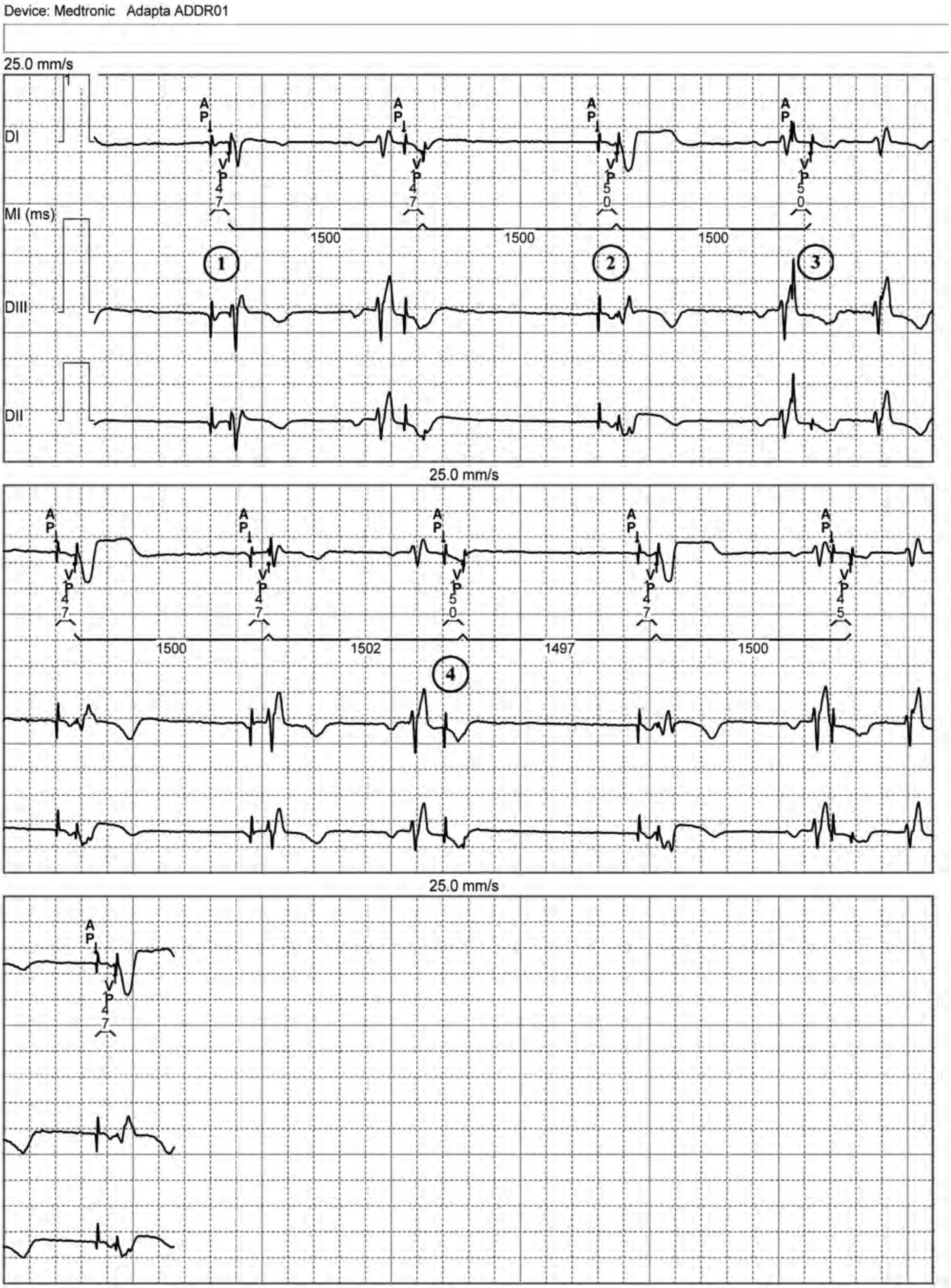
1: AV pacing; fusion between spontaneous and paced ventricular activation;
2: AV pacing with effective and complete capture (AP VP);
3: absence of atrial and ventricular sensing with ineffective, asynchronous AV pacing since it falls in the atrial and ventricular refractory periods;
4: new asynchronous AV pacing; the ventricular stimulus falls on the peak of the T wave, during the ventricular vulnerable period, without capture;

Comments

Fixed rate and asynchronous pacing were the only modes available with the original cardiac pacemakers. DOO is an asynchronous AV sequential pacing mode, without inhibition by intrinsic events. This tracing shows, when the patient is not pacemaker-dependent, the development of parasystole and competition between spontaneous and paced activity. This mode allows a verification of the reliability of capture, and prevents inhibition when the pacemaker is exposed to outside interference (e.g. by an electrical scalpel) in pacemaker-dependent patients. Pacing is effective and captures the atrium or the ventricle when it occurs outside the absolute, physiologic refractory period that follows a spontaneous atrial or ventricular event.

This tracing illustrates the risk associated with this type of pacing mode. Several paced ventricular events fall on the peak of the T wave of a spontaneous QRS that was not sensed, i.e. in the vulnerable period, with a risk of induction of ventricular arrhythmias. While the risk of ventricular fibrillation is limited, it increases in presence of myocardial ischaemia or metabolic disorder. Similarly, asynchronous atrial pacing during the atrial vulnerable period may trigger a bout of AF.

Asynchronous modes are now obsoletes and used in 2 specific circumstances only: 1) a magnet mode; the application of a magnet over the pulse generator triggers A00, V00 or DOO pacing, depending of the device programming; 2) test mode: the DOO mode can be programmed temporarily for MRI-compatible pacemaker-dependent patients who need to undergo MR examinations. One must, of course, not forget to re-interrogate and reprogram the pacemaker after the examination.


Device: Medtronic Adapta ADDR01
25.0 mm/s
DI
MI (ms)
DIII
DII
AP
VP
47
50
45
1500
1502
1497
1
2
3
4
25.0 mm/s
25.0 mm/s

Case 3: Triggered modes

Patient

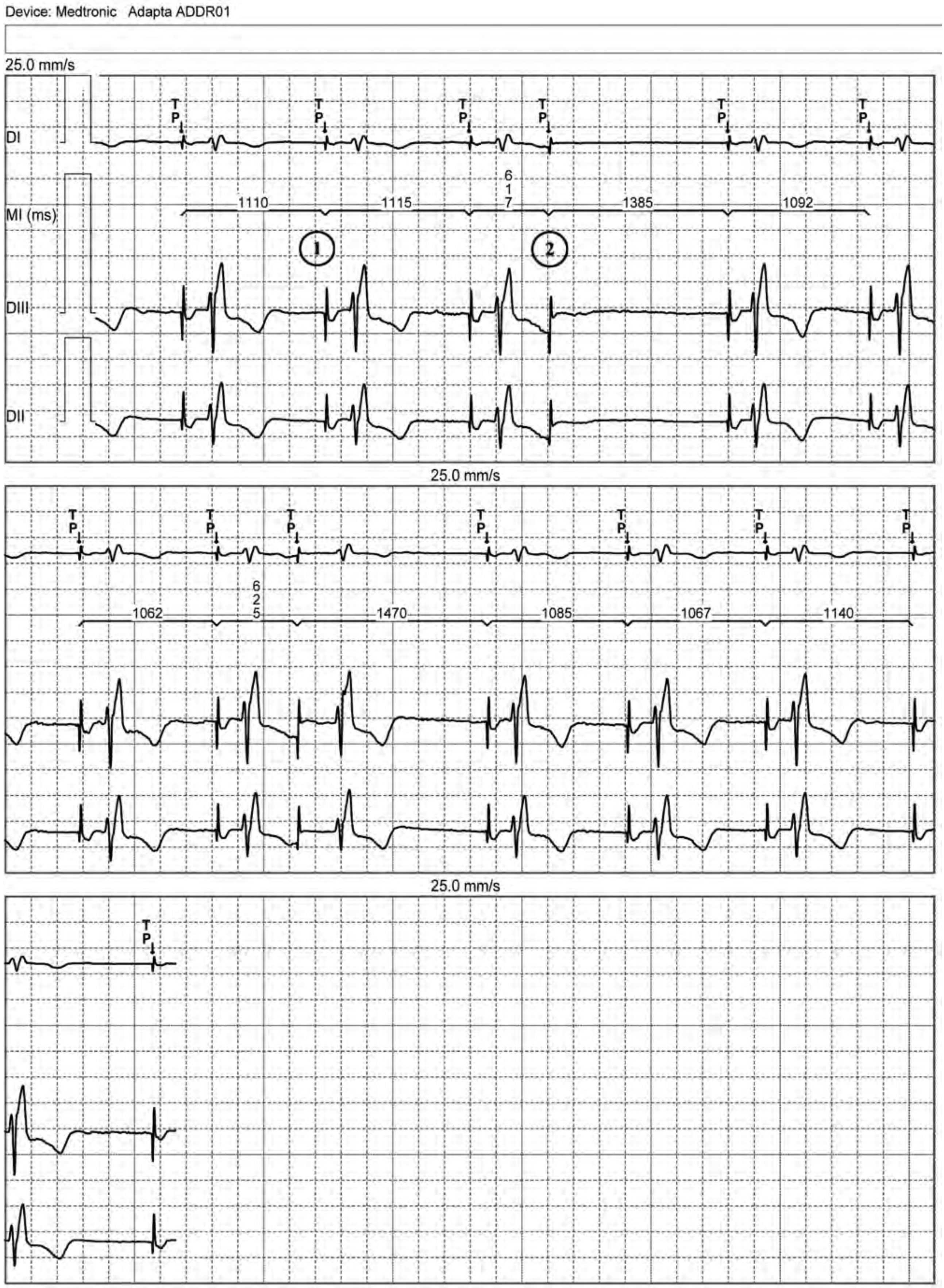
Same patient as in Case 1.

EGM

Tracing 3a: mode AAT programmed at 40 bpm;
1: accurate sensing of spontaneous atrial activity triggering atrial pacing (TP = Triggered Pacing);
2: proper sensing of atrial extrasystole triggering atrial pacing (TP);
Tracing 3b: programmed in AAT mode at 60 bpm;
3: atrial pacing at the backup rate (AP);
4: proper sensing of atrial extrasystole triggering atrial pacing (TP);
Tracing 3c: programmed in VVT mode at 40 bpm;
5: proper sensing of spontaneous ventricular activity and ventricular pacing (TP); absence of capture and ECG similar to the spontaneous morphology;
6: non-conducted atrial extrasystole with compensatory pause; at the end of the escape interval (1,500 ms after ventricular sensing), the ventricle is paced at the backup rate (VP);
7: fusion between spontaneous and ventricular paced complex.

Comments

Except for pacing triggered by sensed events, the triggered modes function like the corresponding inhibited modes and can be applied in 2 specific cases:
1) When sensing myopotentials or electromagnetic interference, the SST mode, instead of being inhibited, issues a paced event in response to each artifact sensed outside the refractory period, which prevents the occurrence of a pause in pacemaker-dependent patients. To prevent runaway pacing, one can, depending on the device model, either lengthen the refractory period or limit the upper pacing rate. This type of pacing mode was valuable in older pacemaker models, which were more sensitive to outside interferences because they functioned strictly in unipolar mode.
2) This mode allows a) an evaluation of sensing in the chamber concerned, b) a confirmation of the absence of crosstalk, and c) the proper sensing of extrasystoles. On this tracing, for example, the AAT mode enables the verification of a) accurate sensing of sinus activity, b) proper sensing of atrial extrasystoles, and c) absence of crosstalk.
It is noteworthy that on the 3c tracing (5) the QRS complex is not sensed at its onset. Sensing is, indeed, possible when the pacemaker has measured a greater ventricular signal amplitude than the programmed sensitivity value with a signal slope falling within the range of frequency between 20-30 and 80-125 Hz.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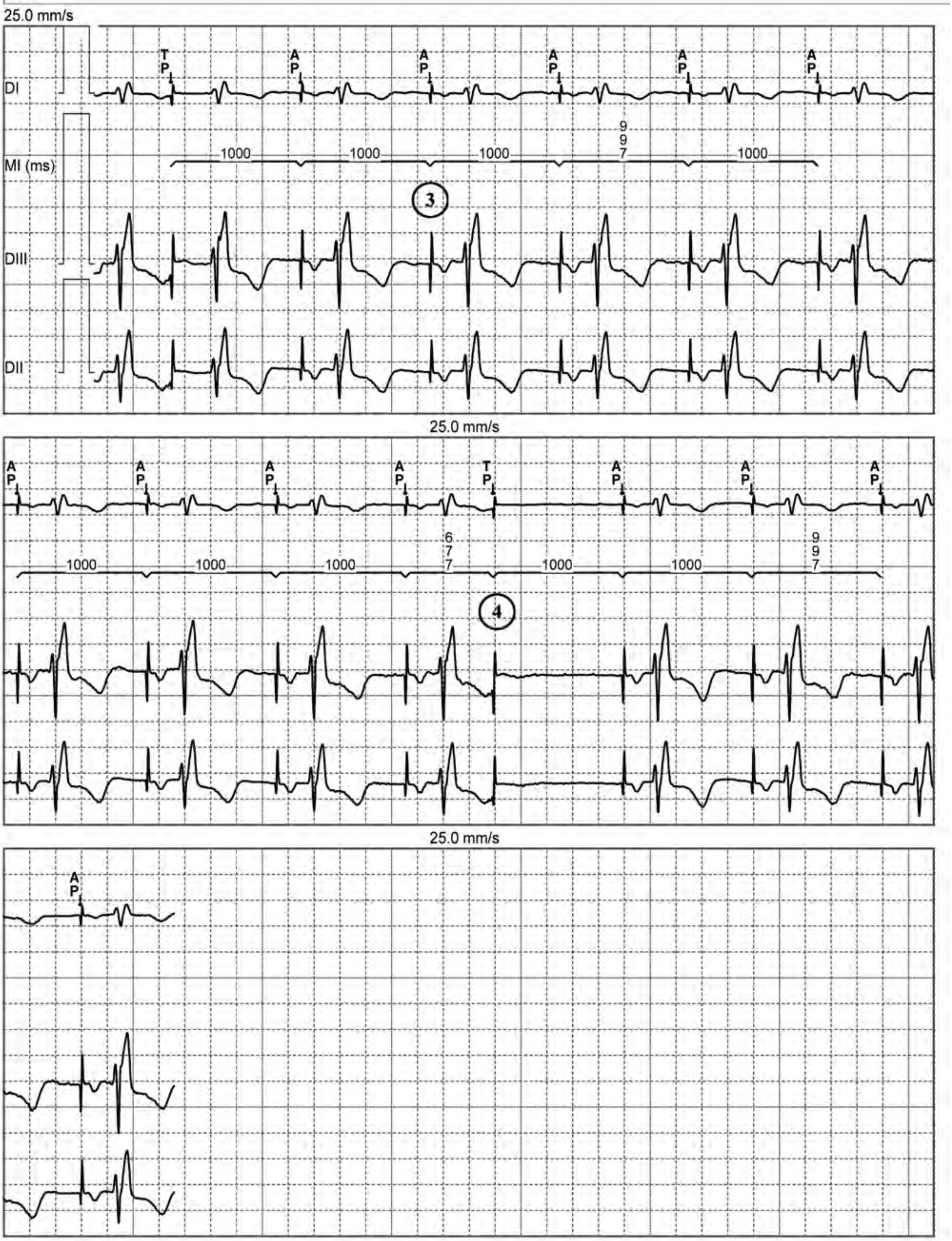
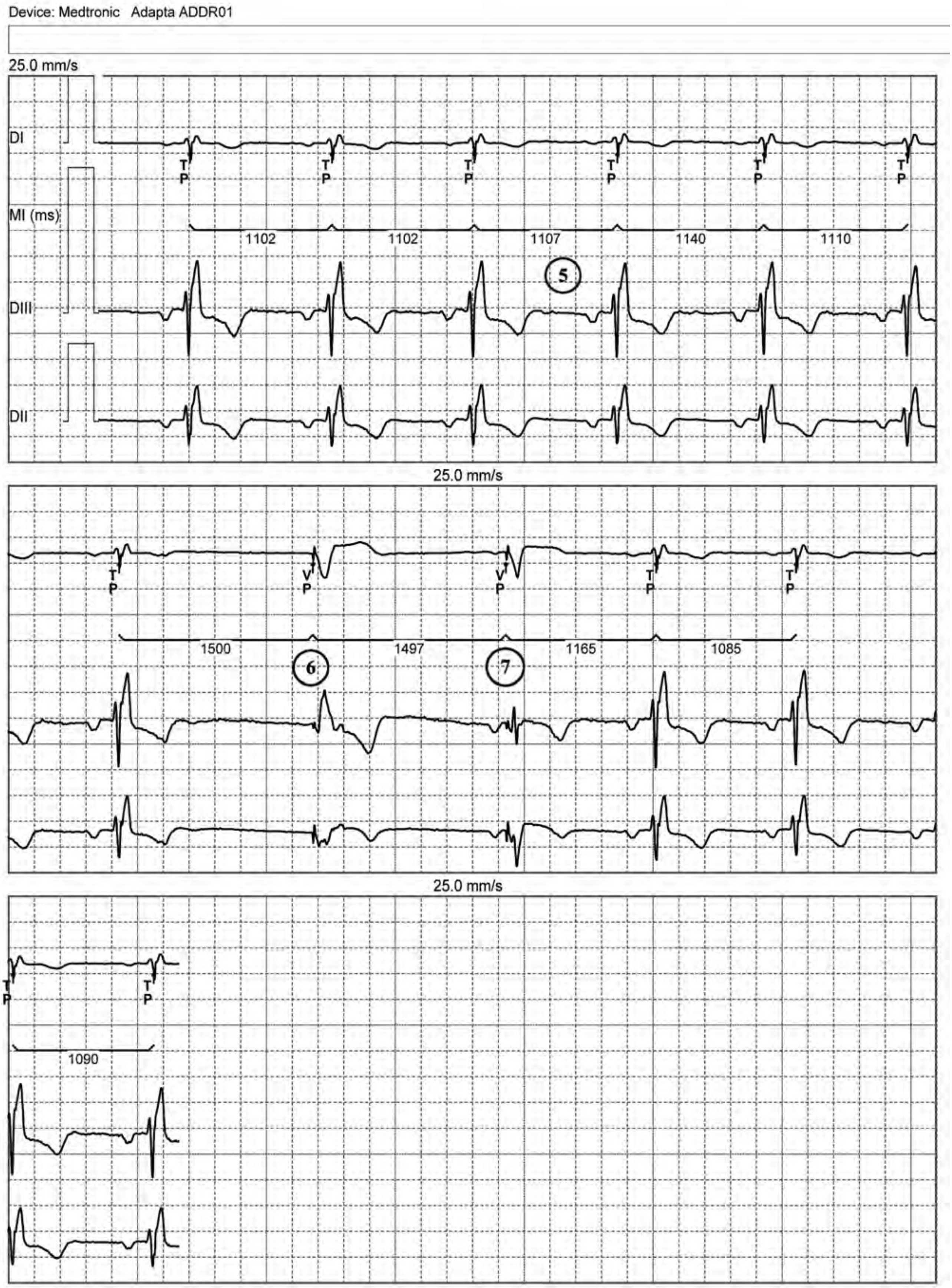
25.0 mm/s
DI
MI (ms)
DIII
DII
T
P
1110
1115
6
1
7
1385
1092
1
2
25.0 mm/s
1062
6
2
5
1470
1085
1067
1140
25.0 mm/s

Device: Medtronic Adapta ADDR01




Device: Medtronic Adapta ADDR01
25.0 mm/s
DI
MI (ms)
DIII
DII
T P
1102
1102
1107
1140
1110
5
25.0 mm/s
T P
V P
1500
1497
1165
1085
6
7
25.0 mm/s
1090

Case 4: Single chamber AAI mode

Patient

Same patient as in Case 1.

EGM

Mode AAI programmed at 60 bpm.

1: atrial pacing (AP) at the backup rate at the end of the 1,000 ms escape cycle between 2 atrial paced events;

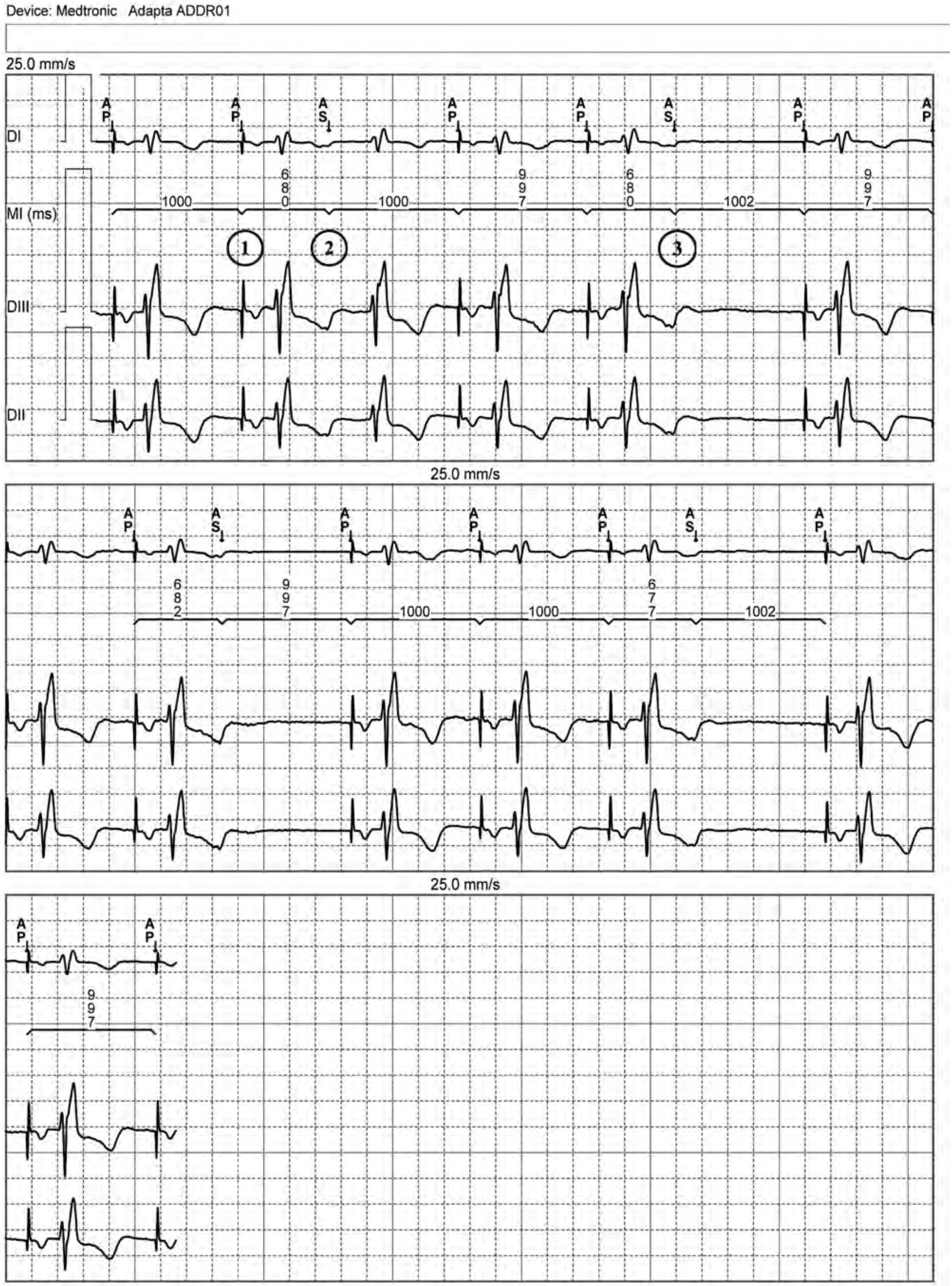
2: accurate sensing of an atrial extrasystole (AS) and resetting of the atrial escape cycle;

3: accurately sensed blocked atrial extrasystole, though not followed by ventricular pacing; resetting of the atrial escape cycle ending with an atrial paced event in absence of other sensed atrial event;

Comments

A single chamber pacemaker functions in AAI mode when one lead is placed in the atrium; this mode can also be programmed in a dual chamber device. This tracing illustrates the main characteristics of this pacing mode: 1) atrial sensing and pacing, inhibited by a spontaneous atrial event; the preferred indication is, therefore, isolated sinus dysfunction in absence of ventricular conduction abnormalities. An AAI pacemaker allows a) a limitation of the number of implanted leads, b) the guarantee of a physiologic heart rate at rest as well as during exercise after the programming of rate responsiveness, and c) the elimination of all unnecessary ventricular pacing; 2) absence of ventricular sensing or pacing. Single chamber AAI pacemakers or the programming of AAI mode in a dual chamber pacemaker are strictly contraindicated in patients who present with permanent or paroxysmal disorders of AV conduction. It must also be avoided in patients presenting with vagal manifestations or carotid sinus syndrome. This tracing shows ventricular pauses coinciding with the occurrence of blocked atrial extrasystole.

A recent study reported unfavorable results from the implantation of a single chamber AAI pacemaker compared with a dual chamber device in patients presenting with sinus node dysfunction. The rate of re-intervention was higher in recipients of AAI pacemakers, who needed an additional ventricular lead when AV conduction disorders developed. Therefore, the indications for the implantation of a single chamber AAI pacemaker are currently relatively limited.


Device: Medtronic Adapta ADDR01
25.0 mm/s
DI
MI (ms)
DIII
DII
AP
AS
1000
680
997
1002
682
677
1
2
3

Case 5: Single chamber VVI mode SINGLE CHAMBER VVI

Patient

Same patient as in tracing no 1.

EGM

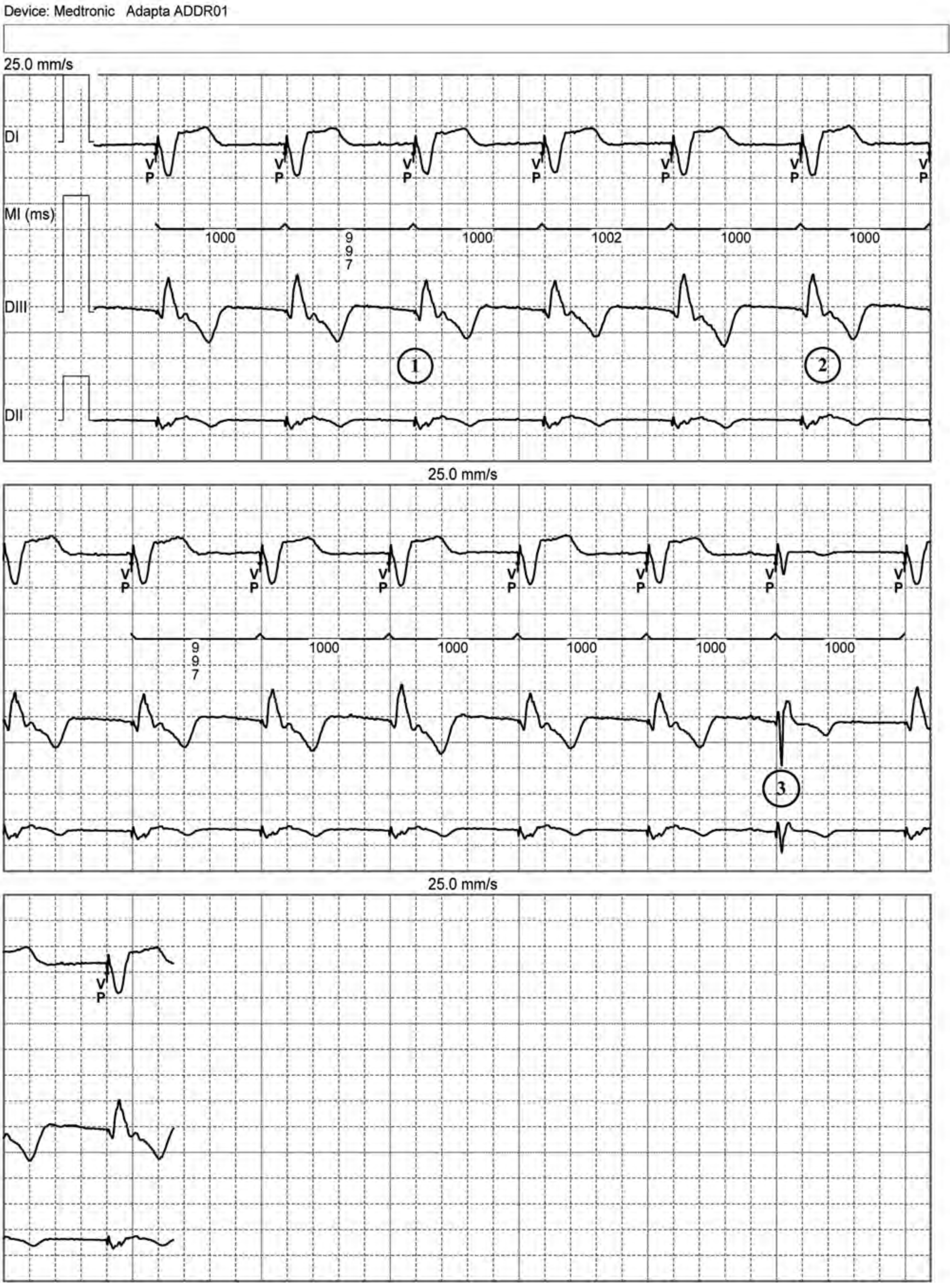
Tracing 5a: VVI mode programmed at 60 bpm;
- 1: ventricular pacing at the backup rate (1,000 ms between VP);
- 2: retrograde atrial conduction in 1:1;
- 3: fusion with spontaneous activation;

Tracing 5b: VVI mode programmed at 40 bpm;
- 4: spontaneous ventricular sensing and inhibition of ventricular pacing; resetting of the escape cycle with each sensed ventricular event;

Comments

A single chamber pacemaker operates in VVI mode when a single lead is implanted in the ventricle; this mode can also be programmed with a dual chamber pacemaker. For this patient, the programming of the backup rate is critical. Indeed, at 60 bpm, it is too high and associated with incessant ventricular pacing and reversal of the physiologic AV activation sequence. The ECG shows retrograde conduction with possible pacemaker syndrome. Atrial contraction occurs nearly synchronously with ventricular contraction, when the AV valves are closed, causing retrograde flow toward the pulmonary veins and the vena cava. The pacemaker syndrome stems from a complex interplay among hemodynamic, neurohumoral and vascular changes, secondary to the loss of AV synchrony. Symptoms develop that may be highly disabling, due to an increase in atrial and systemic venous pressure, including dyspnea, orthopnea, neck and thoracic pulsations, palpitations, and chest pain.

In contrast, at 40 bpm, the backup rate is below the lowest spontaneous rate, and no pacing occurs, which 1) lowers the battery consumption and prolongs its life, 2) prevents retrograde conduction, and 3) effectively paces only upon the occurrence of paroxysmal AV conduction disorders. This programming (VVI 40 bpm) is acceptable given this patient’s characteristics.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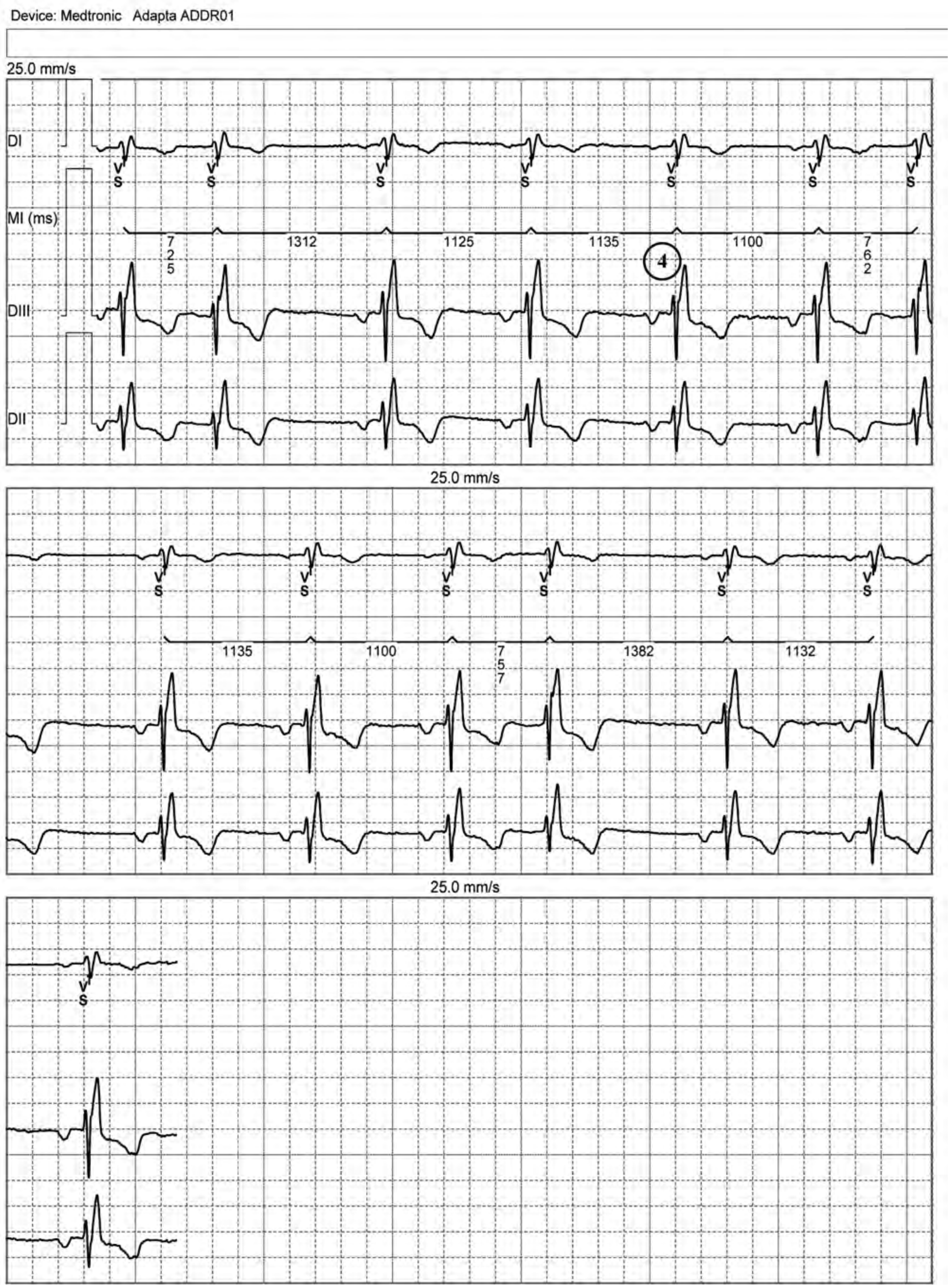
25.0 mm/s
DI
MI (ms)
DIII
DII
VP
1000
997
1000
1002
1000
1000
1
2
25.0 mm/s
VP
997
1000
1000
1000
1000
1000
3
25.0 mm/s
VP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25.0 mm/s
DI
VS VS VS VS VS VS VS
MI (ms)
725 1312 1125 1135 1100 762
4
DIII
DII
25.0 mm/s
VS VS VS VS VS VS
1135 1100 757 1382 1132
25.0 mm/s
VS

Case 6: Dual chamber VDD mode

Patient

Same patient as in Case 1.

EGM

Tracing 6a: VDD mode programmed at 60 bpm;

1: atrial sensing (AS) and ventricular pacing (VP);

2: slowing of atrial rate and ventricular pacing at the backup rate (1,000 ms between 2 VP) without atrial pacing; retrograde atrial conduction sensed in the post-ventricular atrial refractory period (AR), which initiates neither an AV delay nor ventricular pacing;

Tracing 6b: VDD mode programmed at 40 bpm;

3: accurate sensing of atrial depolarization (AS) and ventricular pacing (VP); slowing of the backup rate prevents a) all ventricular pacing that is non synchronized to atrial sensing, and b) retrograde conduction in this patient;

4: proper sensing of atrial extrasystole and synchronized ventricular pacing;

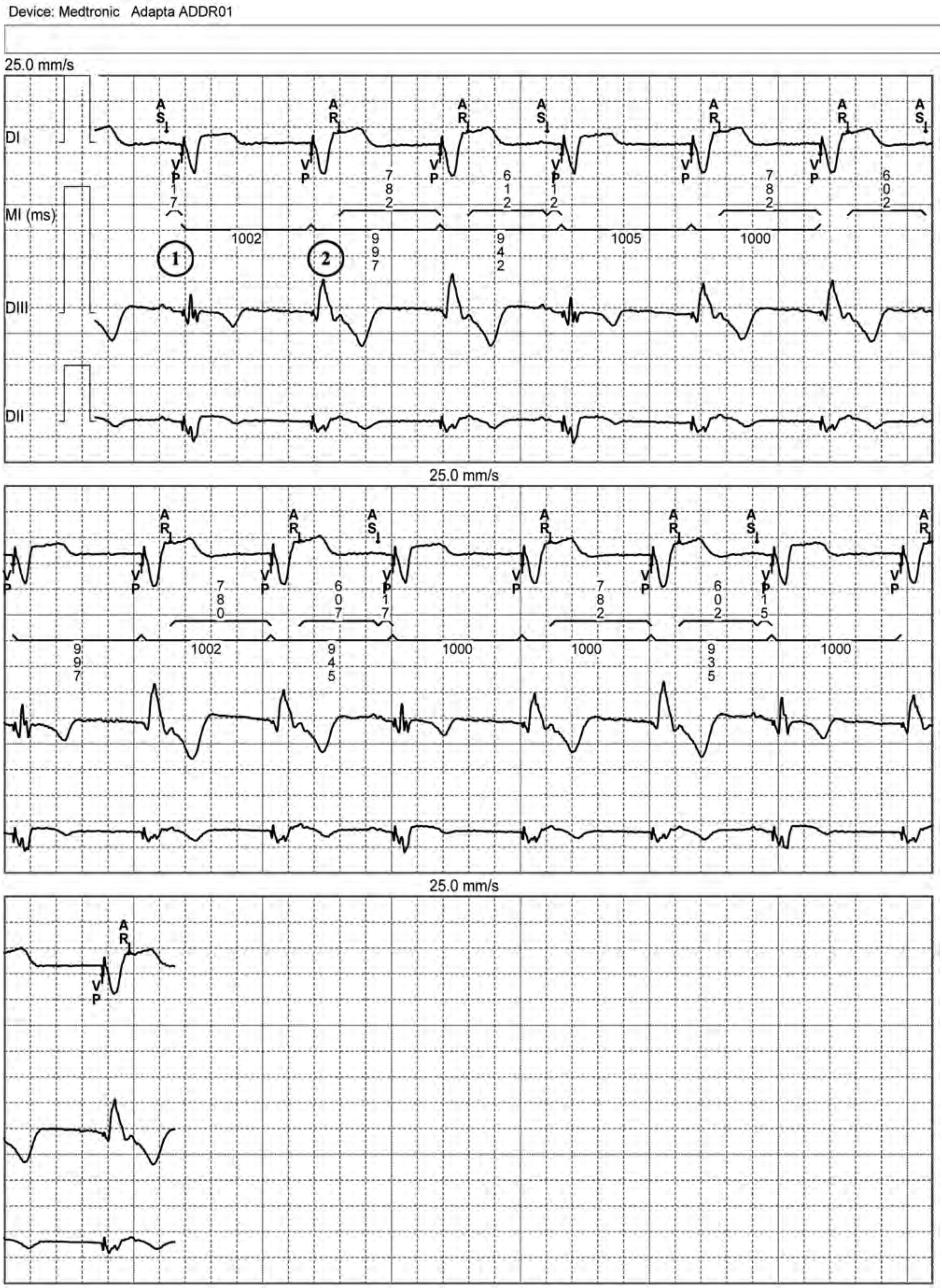
Comments

The VDD mode can be programmed in a standard dual chamber pacemaker as well as in a single lead, dual chamber VDD device equipped with a) two floating (orthogonal) atrial electrodes to accomplish atrial sensing, and b) pacing/sensing bipolar ventricular electrodes. However, atrial pacing is precluded. Thus, this mode is acceptable in the absence of sinus node dysfunction, along with the programming of a slow backup rate, perhaps with a rate hysteresis to prevent VVI pacing. In this tracing, programming at 60 bpm was associated with retrograde conduction, which was sensed in the post-ventricular atrial refractory period (PVARP) and, consequently, did not trigger a pacemaker-mediated tachycardia (PMT). A PMT prevention algorithm as well as fallback must be programmed.

The advantages of the single lead VDD systems are 1) the need for a single lead, which might limit the number of leads implanted and to shorten the implantation procedure, 2) the absence of injury to, and fibrotic development in the atrial wall, and 3) in patients whose sinus node function is preserved, the normal AV activation sequence is undisturbed.

The disadvantages of single lead VDD systems are 1) an occasionally suboptimal atrial sensing compared with a separate atrial lead, as the atrial dipole might move away from the wall, particularly during deep inspiration or cardiac motion, 2) likewise, the sensing of atrial arrhythmias might be poor for the same reasons, making stored information less reliable, 3) in case of paroxysmal, exercise-induced loss of atrial sensing and of AV block, the pacing rate reverts to backup with a possible abrupt fall in heart rate, possible pacemaker syndrome and risk of PMT, and 4) this mode must be avoided in presence of sinus node dysfunction.

The preferred indication for the VDD mode is, therefore, complete AV block with a preserved sinus node function.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25.0 mm/s
DI
MI (ms)
DIII
DII
1
2
1002
997
942
1005
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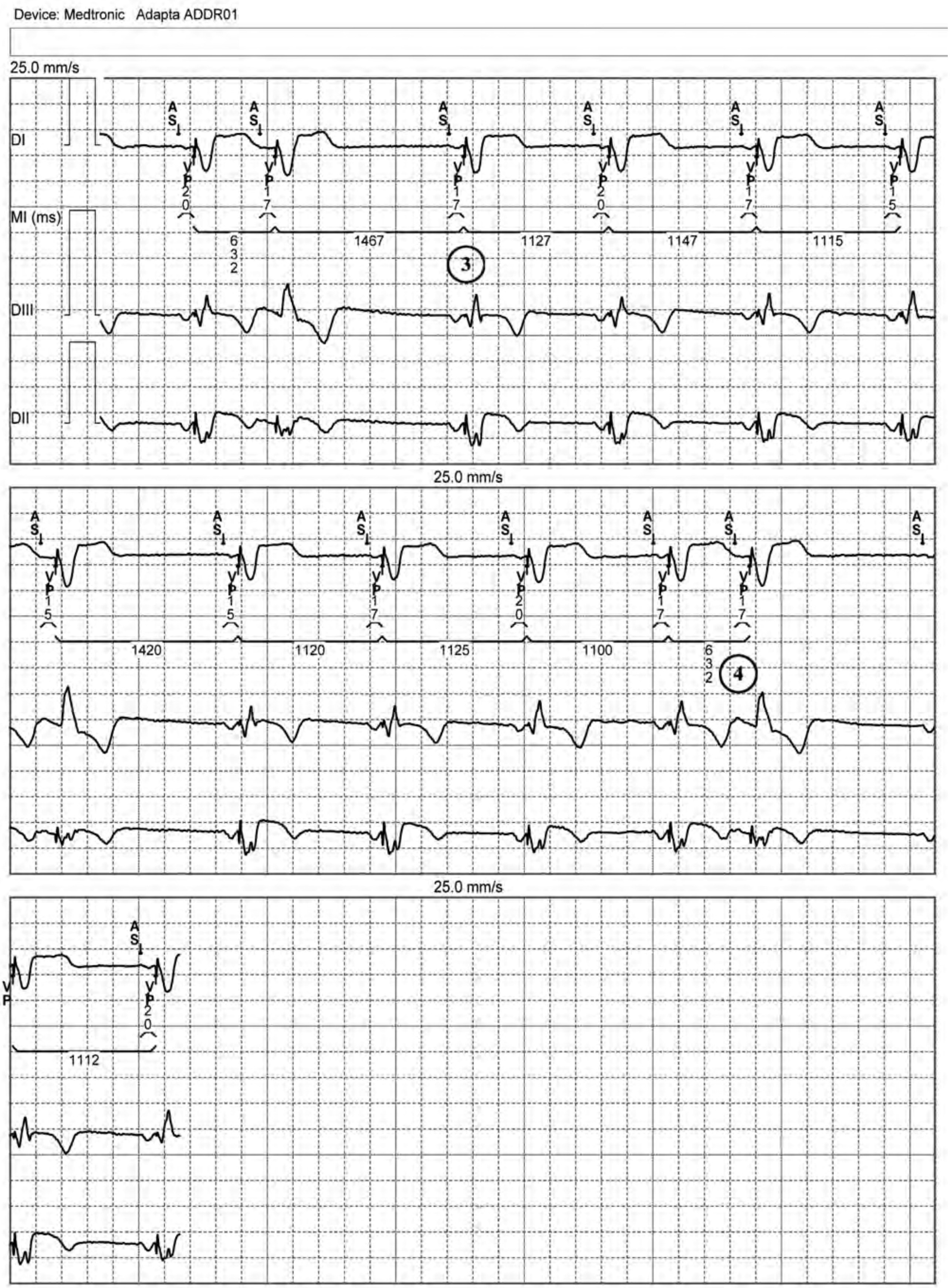
25.0 mm/s
25.0 mm/s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25.0 mm/s
DI
MI (ms)
DIII
DII
AS
VP
632
1467
1127
1147
1115
3
25.0 mm/s
1420
1120
1125
1100
632
4
25.0 mm/s
1112

Case 7: Dual chamber DDI mode

Patient

Same patient as in Case 1.

EGM

Tracing 7a: DDI mode programmed at 60 bpm;

1: atrial (AP) and ventricular pacing (VP) at the backup rate;

2: acceleration of the spontaneous atrial rhythm which is sensed (AS) and does not cause an AV delay; non-atrial synchronized ventricular pacing (pseudo-VVI) at the end of the ventricular pacing interval; inhibition of atrial pacing during on-going cardiac cycle;

3: spontaneous atrial and ventricular rhythm: inhibition of atrial and ventricular pacing; resetting of the pacing interval from ventricular sensing;

4: fusion with the spontaneous ventricular rhythm;

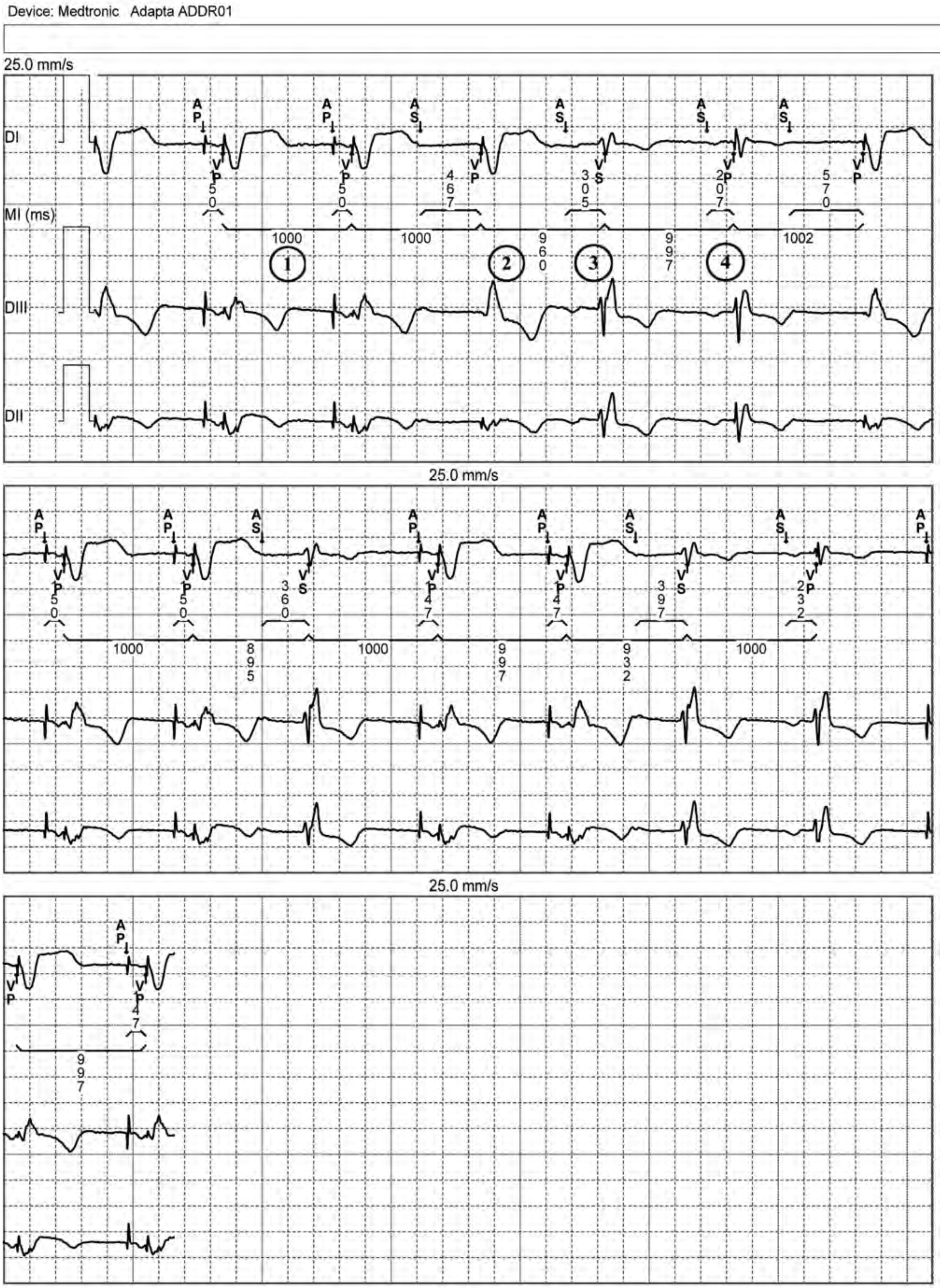
Tracing 7b: DDI mode programmed at 70 bpm;

5: continuous AV pacing (AP VP); the spontaneous atrial rhythm is consistently overdriven by atrial pacing; it is noteworthy that this accelerated atrial pacing also suppresses the atrial extrasystoles;

Comments

The DDI mode provides sequential dual chamber AV pacing, with atrial as well as ventricular sensing, though without trigger by sensed atrial events. AV synchrony is guaranteed only at the rate of on-going atrial pacing (backup rate, rate responsive or smoothed rate). If the spontaneous atrial rate is faster than the atrial pacing rate, the latter is inhibited and no AV delay is initiated; when the atria are activated spontaneously, AV synchronization is absent. Thus, in case of AV block, the spontaneously activated atria do not synchronize with ventricular pacing if their rate is faster than the ongoing atrial pacing: the function is the same as a VVI mode. This explains the absence of runaway ventricular pacing in case of detection of an atrial arrhythmia, or the use of DDI as a fallback mode. It is also the function of choice when the pacemaker does not accurately detect atrial arrhythmias and does not properly fallback and paces the ventricle erratically. It is not a wise choice for a patient who presents with AV block and normal sinus function because the mode is incapable of p-synchronous pacing, although it may be acceptable for a patient presenting with AV block, even if permanent, who also suffers from sinus node dysfunction and persistent atrial pacing (since atrial pacing synchronizes ventricular pacing). An adjustment of the backup rate is, therefore, essential, and must be a) relatively rapid in order to prevent the onset of spontaneous atrial activation, and b) associated with rate responsiveness. In this patient, a rate programmed at 70 bpm allowed satisfactory AV synchrony, at least at rest.

The ideal indication for this type of pacing mode is a patient presenting with AV block and bradycardia-tachycardia syndrome, combining AF (no risk of runaway) and incessant sinus node dysfunction after the end of the AF episode (AP VP pacing).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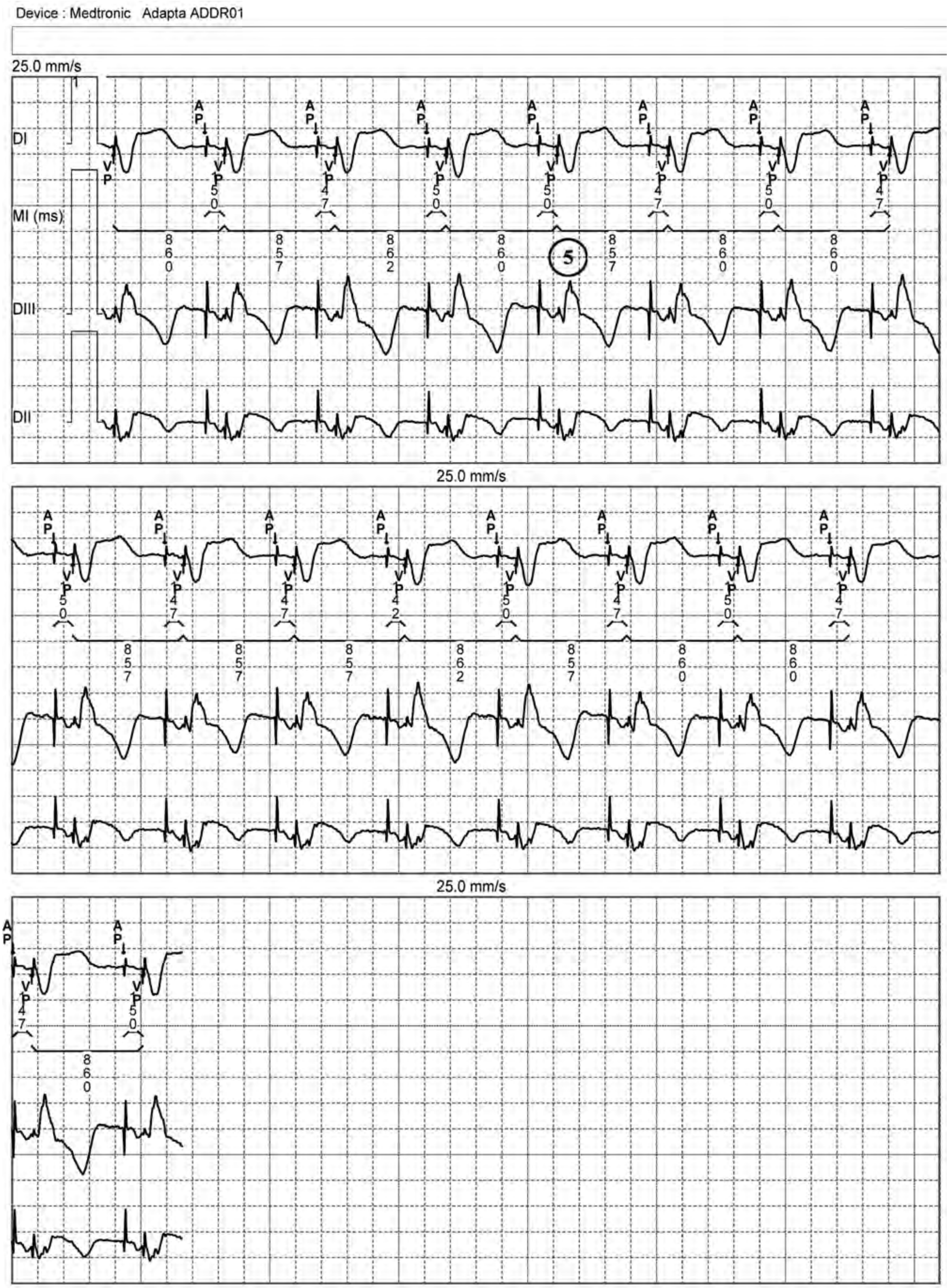
25.0 mm/s
DI
MI (ms)
DIII
DII
AP
VP
AS
VS
50
467
305
207
570
1000
1000
960
997
1002
1
2
3
4
25.0 mm/s
360
47
397
232
1000
895
1000
997
932
1000
25.0 mm/s
47
997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25.0 mm/s
DI
MI (ms)
DIII
DII
5
25.0 mm/s
25.0 mm/s

CASE 8: PACING IN DDD MODE

Patient

Same patient as in Case 1.

EGM

Tracing: DDD mode programmed at 60 bpm;

1: atrial sensing (AS) and ventricular pacing (VP); the AV delay after a spontaneous atrial event is 120 ms;

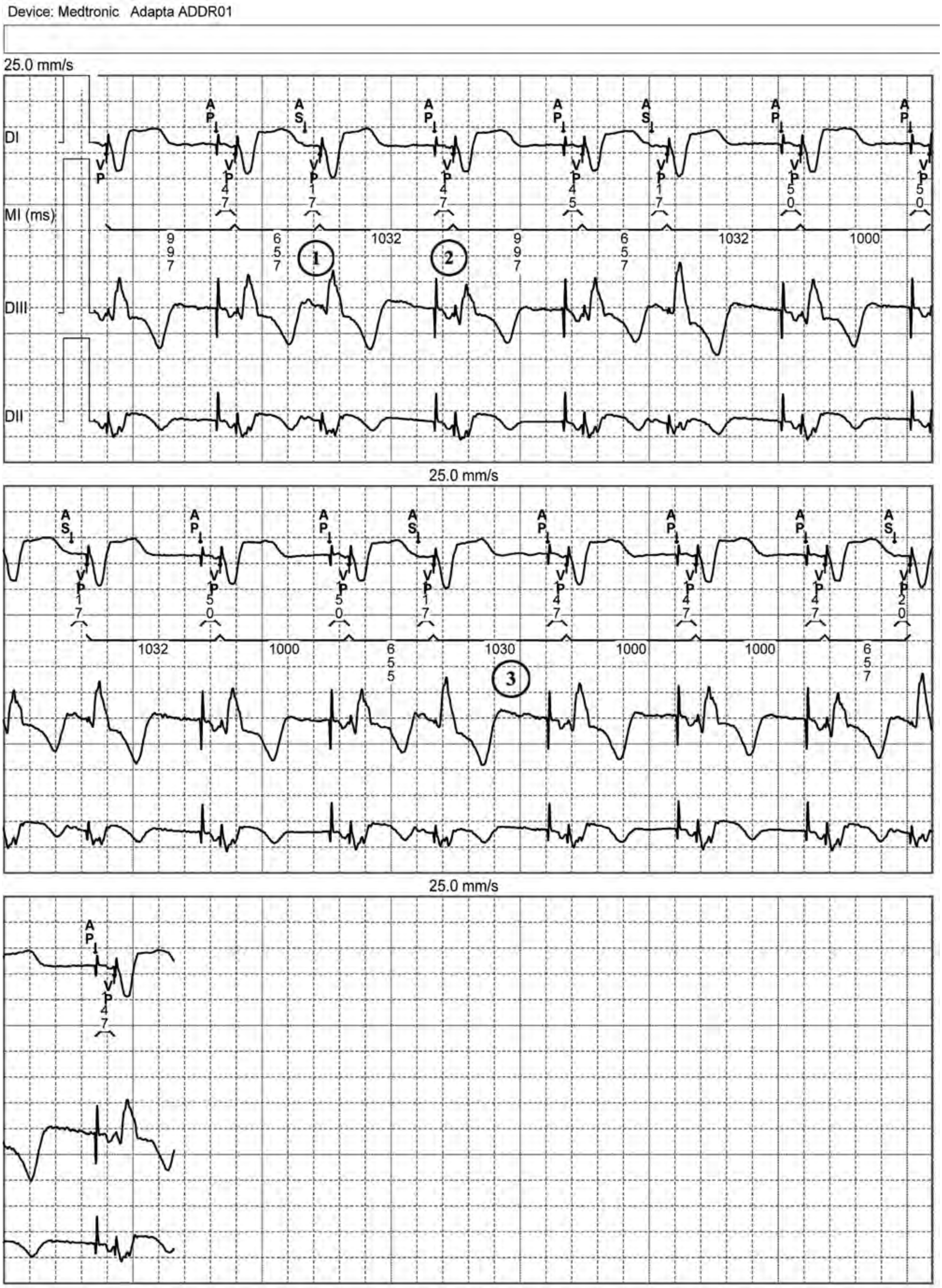
2: AV pacing; the AV delay after a paced atrial event is 150 ms;

3: during alternation between AS-VP and AP-VP, the interval between 2 VP is 30 ms longer than the programmed value, corresponding to the backup rate; these 30 additional ms represent the difference between spontaneous and paced AV delay;

Comments

The fundamental principle of the DDD mode consists in synchronizing ventricular pacing with atrial sensing (triggered function) or pacing. A spontaneous atrial or ventricular event sensed outside the refractory period inhibits atrial or ventricular pacing (inhibited function). Consequently, this mode allows the preservation of atrial synchrony between low and high (upper rate limit) sinus rates. All atrial events sensed outside the refractory period between backup and maximum synchronous rate or atrial pacing initiates the AV delay with ventricular pacing in absence of spontaneous ventricular sensing.

Therefore, the programming of DDD mode seems appropriate for this patient. The follow-up would probably reveal nearly 100% ventricular pacing, i.e. apparently normal and desirable function. An analysis in ODO mode, however, revealed normal AV conduction. One of the priorities, when programming a pacemaker, is to eliminate all unnecessary ventricular pacing, allowing a) the sparing of significant battery consumption and the prolongation of the pulse generator longevity, and b) above all, to limit right ventricular pacing, which, on the short, intermediate and long term, is associated with potential deleterious hemodynamic effects, as well as ventricular remodeling and development of atrial arrhythmias. Right ventricular pacing causes an asynchronous sequence of inter- and intraventricular activation and relaxation. A high percentage of ventricular paced events in a patient presenting with preserved AV conduction should be noted at the time of device interrogation and initiate implementation of specific ventricular pacing avoidance algorithms.


Device: Medtronic Adapta ADDR01
25.0 mm/s
DI
MI (ms)
DIII
DII
AP
AS
VP
997
657
1032
1000
655
1030
1
2
3

Case 9: pacing in MVP mode

Patient

Same patient as in Case 1.

EGM

Tracing 9a: MVP mode programmed at 70 bpm;

1: permanent atrial pacing with spontaneous conduction and AR interval of approximately 320 ms;

Tracing 9b: MVP mode programmed at 60 bpm;

2: operation identical to the previous tracing (AP-VS); the interval is slightly shorter;
3: atrial extrasystole sensed outside the refractory period, thus labelled AS; blocked atrial extrasystole;
4: atrial pacing at the backup rate; ventricular safety pacing 80 ms after atrial pacing (AP-VP);
5: absence of switch to DDD mode because of absence of other blocked P wave; operation in AAI mode;

Tracing 9c: programming unchanged;

6: first non-conducted atrial event;
7: pacing AP-VP with short AV delay at 80 ms;
8: atrial pacing with conduction to the ventricle (AP-VS);
9: repeat blocked atrial event;
10: AP-VP pacing with short AV delay at 80 ms;
11: switch to DDD mode with paced AV delay at 200 ms; a ventricular event is missing to 2 of the 4 most recent A-A intervals;

Tracing 9d: programming unchanged;

12: pacing in DDD mode;
13: search for spontaneous conduction; in presence of conduction, the mode is switched to AAI;
14: blocked atrial extrasystole;
15: AP-VP pacing with short (80 ms) AV delay;
16: a single blocked, sensed atrial event does not suffice to trigger a new switch to DDD mode;

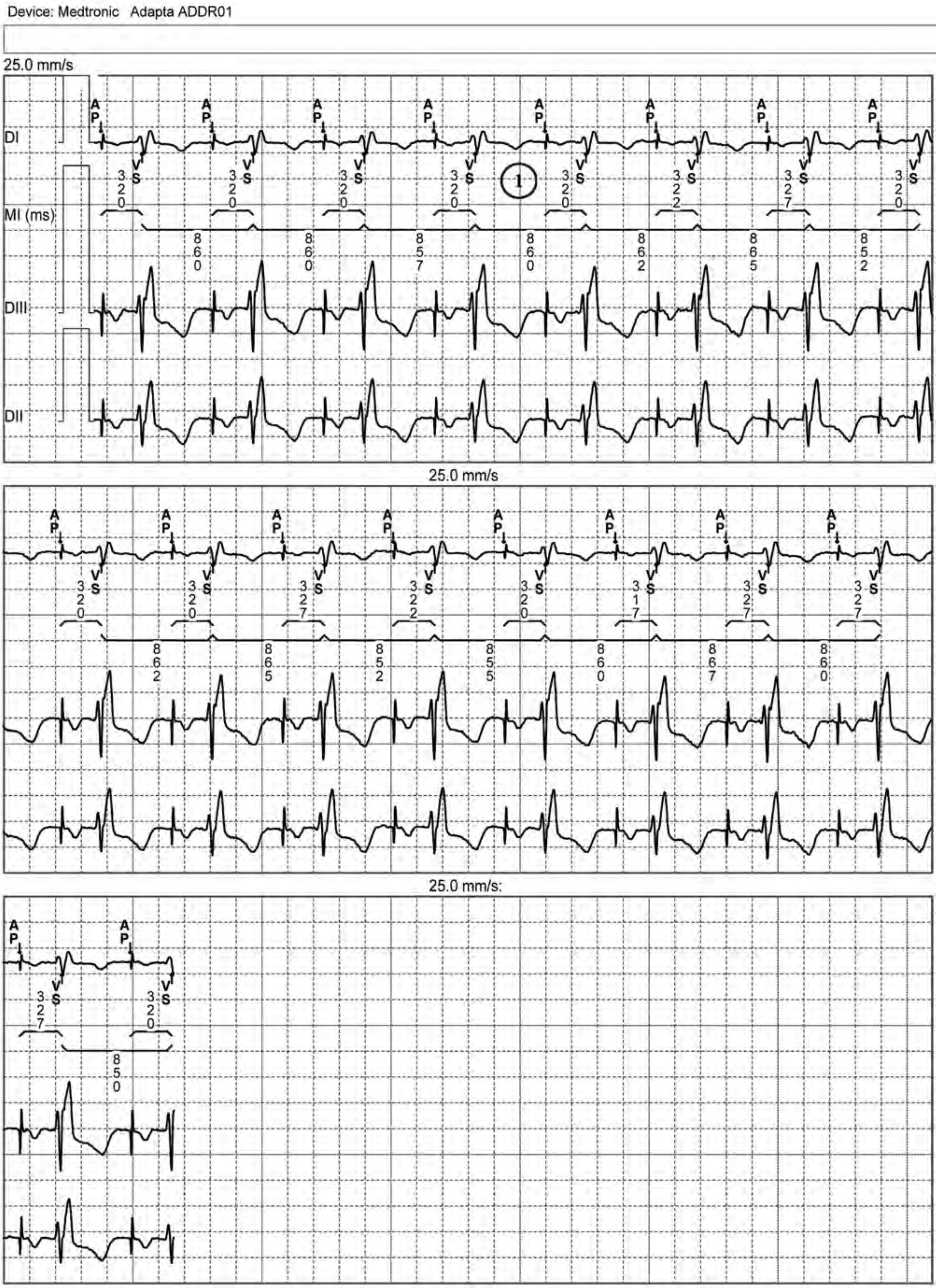
Comments

The appreciation of the adverse effects of right ventricular pacing prompted the development of an AAI platform that automatically switches to DDD mode in presence of AV block, and conversely when conduction returns. These various tracings allow the definition of the different characteristics of the MVP mode:

1) on the first tracing (9a), the main advantage of this algorithm seems evident. Compared with tracing no 8, the programming of this algorithm decreased the proportion of pacing from 100 to 0%. On the long term, this should confer benefits from the standpoint of ventricular remodelling and development of atrial arrhythmias. Percent ventricular pacing is, therefore, an important aspect of the follow-up of patients suffering from sinus node dysfunction, with a view to decrease to a maximum all unnecessary ventricular pacing. It is noteworthy that, on this tracing, the PR interval is relatively prolonged (approximately 300 ms after a paced P wave). In patients with a prolonged PR at rest and during exercise, the pacemaker remains in AAI mode without switching to DDD mode. In presence of symptoms associated with prolongation of the PR interval during exercise, programming to DDD mode seems desirable.

2) on the second tracing (9b), a single blocked atrial event does not prompt a switch to DDD mode. Ventricular safety pacing occurs 80 ms after the following paced atrial event. The longest ventricular pause accepted by the pacemaker corresponds to one half of the slowest programmed rate. To preclude excessively long pauses, it is preferable to not program an excessively slow backup rate.

3) On the third tracing (3c), switch to DDD mode occurs upon repeated interruptions of AV conduction. This relatively rapid switch to DDD mode prevents a succession of pauses and of adverse AP-VP pacing, because associated with a short AV delay (occasionally poorly tolerated by the patient).
4) the last tracing (9d) shows a first confirmation of AV conduction, 1 min after switch to DDD mode. In the first cycle in AAI mode, AV conduction is present (AP -S) and the device switches again to AAI mode.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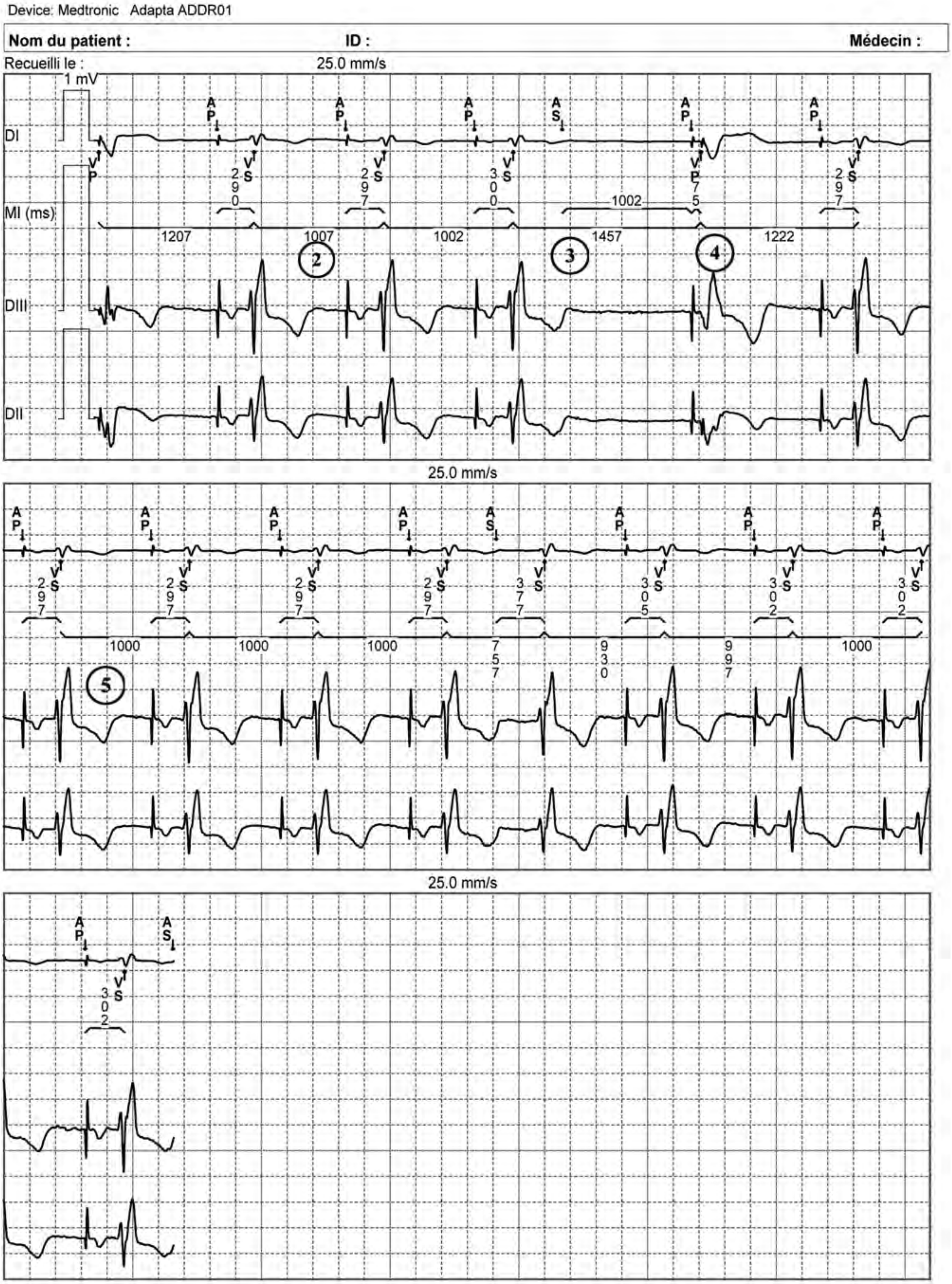
25.0 mm/s
DI
MI (ms)
DIII
DII
AP
VS
320
860
857
862
865
852
1
25.0 mm/s
327
322
317
855
867
25.0 mm/s
850


Device: Medtronic Adapta ADDR01
Nom du patient :
ID :
Médecin :
Recueilli le :
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1 mV
DI
MI (ms)
DIII
DII
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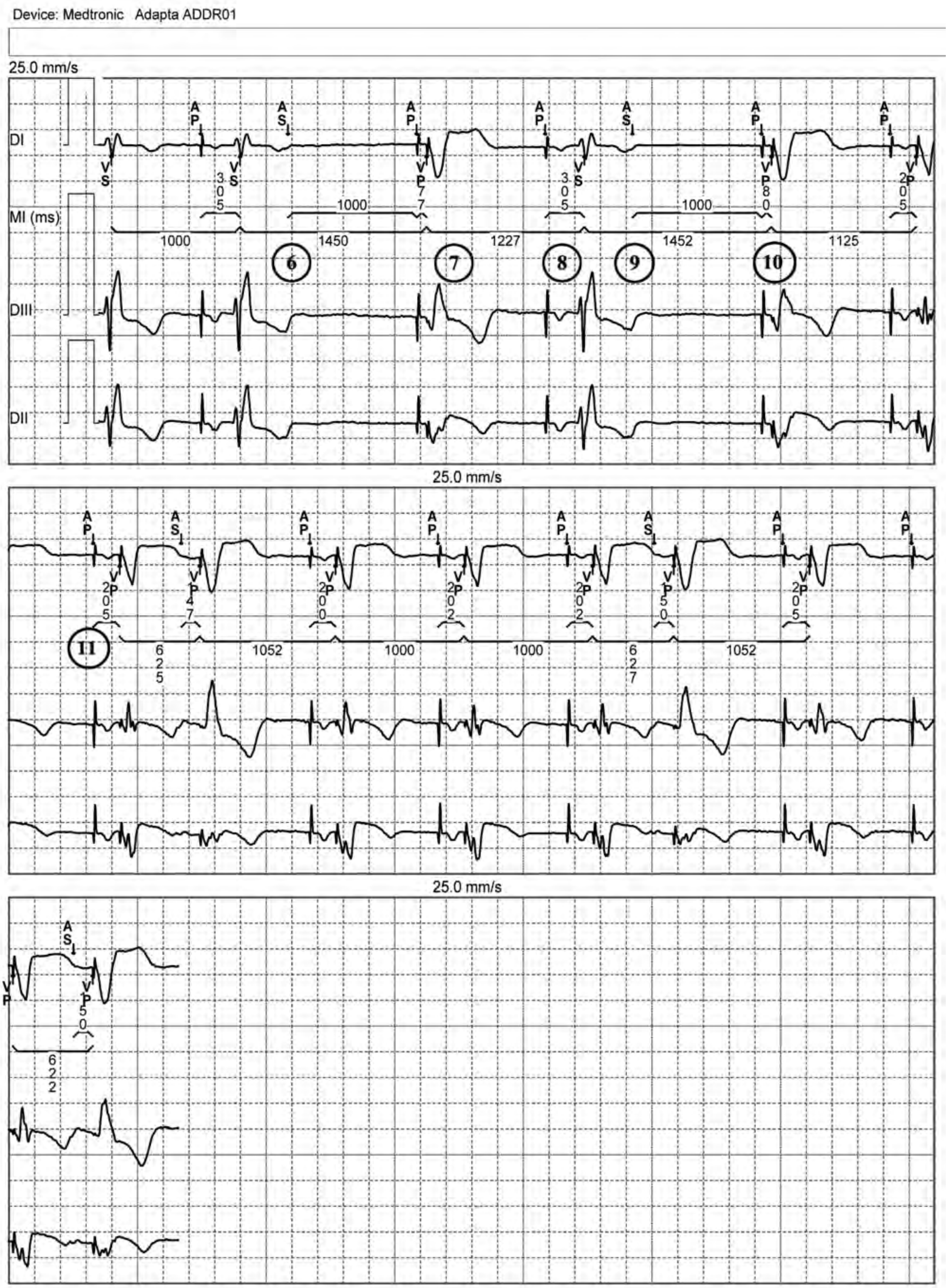
1002
1002
1457
1222
1000
1000
1000
1000
25.0 mm/s
25.0 mm/s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MI (ms)
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DII
AP
AS
VS
VP
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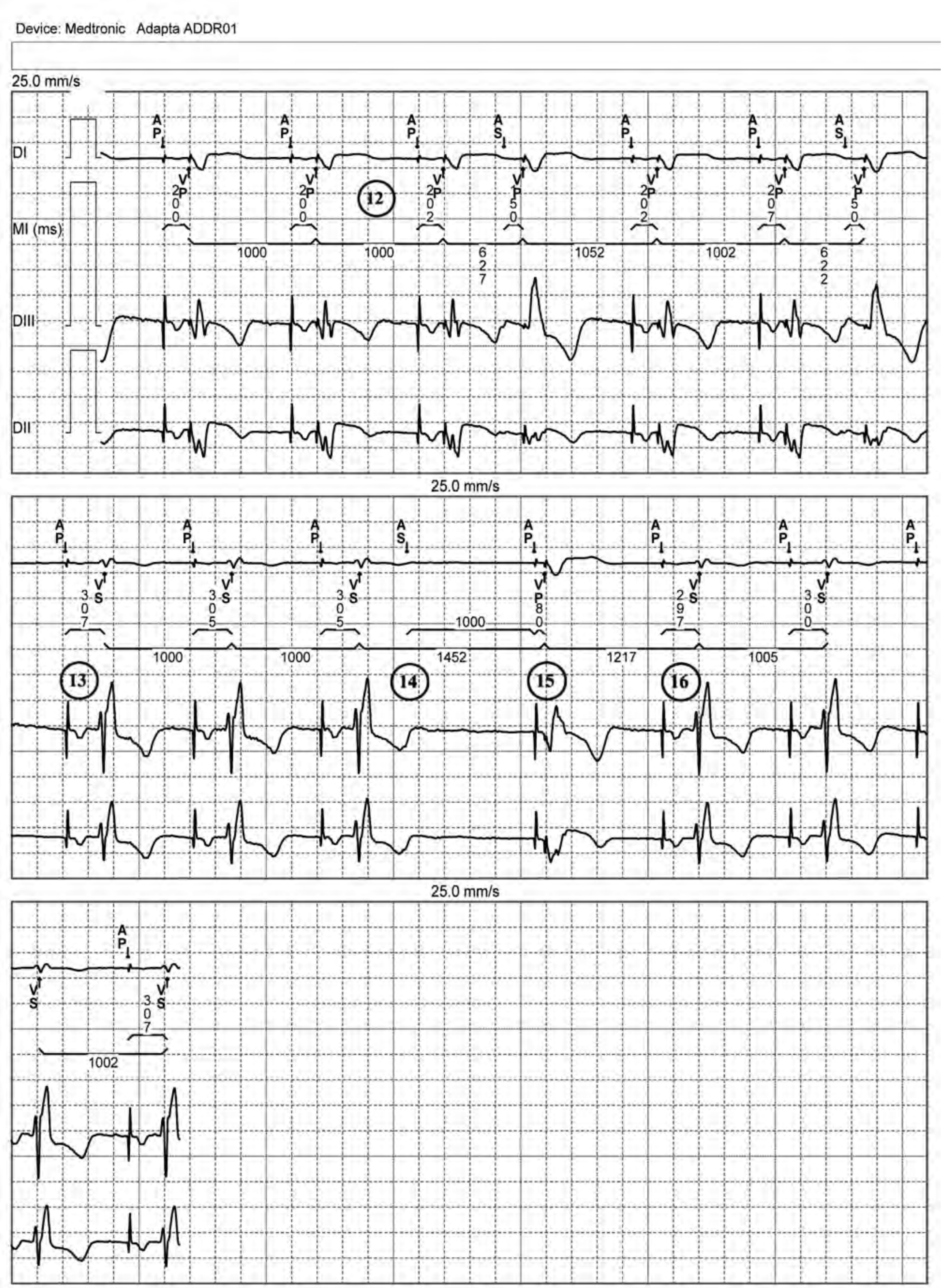
7
8
9
10
11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DII
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13
14
15
16
1000
1000
1452
1217
1005
1002

Case 10: Loss of atrial capture and MVP

Patient

Same patient as in Case 1.

EGM

MVP with decrease in atrial pacing amplitude below the pacing threshold;

1: loss of atrial capture; the following spontaneous atrial activity (a sinus P wave) is labeled AR (refractory period of the preceding atrial paced event); in a first stage, no AP-AP interval without ventricular sensing;

2: AP-AP interval without ventricular sensing; ventricular pacing after a short AV delay;

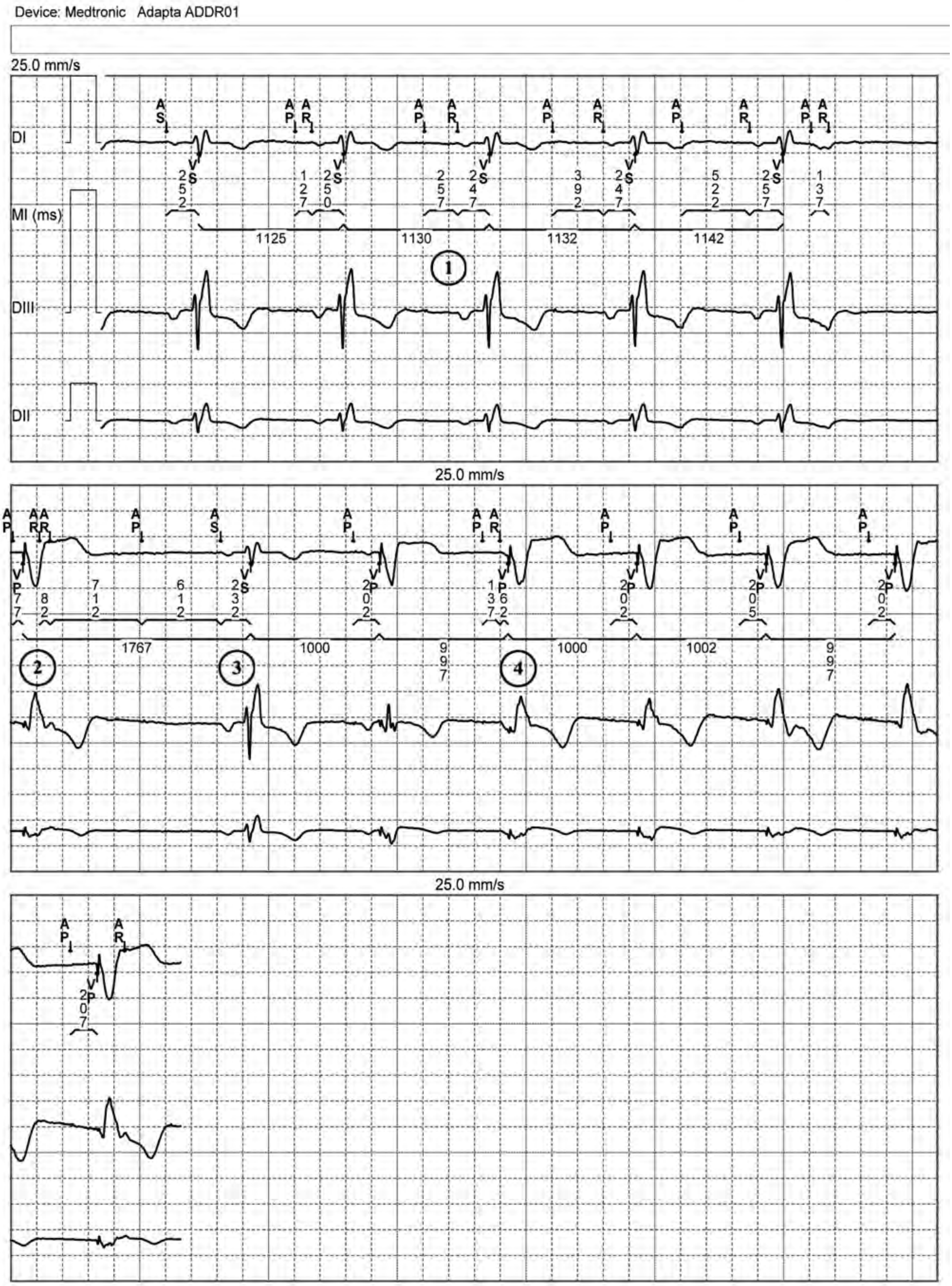
3: blocked AP, conducted AS;

4: switch to DDD mode;

Comments

A proper function of the MVP mode requires accurate atrial and ventricular sensing and proper atrial and ventricular pacing. An abnormality of one of these elements results in dysfunction of the algorithm. In this patient, the pacemaker switches to DDD because of loss of atrial capture.

The setting of the refractory periods requires specific consideration. When the pacemaker operates in AAI mode, the atrial refractory period varies as a function of the ongoing heart rate, and corresponds to 75% of the cardiac cycle, though no longer than 600 ms. In this tracing, the spontaneous atrial events occurring less than 600 ms after atrial pacing (AP) are within the refractory period (AR). The spontaneous atrial events occurring >600 ms after atrial pacing (AP) are not within the refractory period (AS). In the AAI mode, blanking lasts 100 ms in the atrium after sensing or atrial pacing, 80 ms in the ventricle after atrial pacing, and 100 ms in the ventricle after sensing or ventricular pacing.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25.0 mm/s
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MI (ms)
DIII
DII
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1142
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1767
1000
997
1000
1002
997
2
3
4
25.0 mm/s

Pacing & Sensing

Pacing & Sensing

Pacing

Definition of pacing threshold

The pacing threshold is the lowest electrical pulse, delivered outside the natural refractory periods, that consistently elicits the propagation of a depolarizing wavefront. It is measured as voltage amplitude (V) or pulse width (ms).

Chronaxy and rheobase

Lapicques voltage - duration (or chronaxie - rheobase) relationship, expresses the non-linear relation between the threshold voltage and pulse duration. The pacing threshold voltage increases significantly as the pulse duration decreases (in clinical practice below 0.2 ms). All points that are above the curve defined by the threshold voltage - pulse duration relationship are associated with effective capture, whereas all points that are below the curve are associated with absence of capture.

Rheobase is defined as the lowest effective pulse amplitude at an infinite pulse duration (in clinical practice above 2.0 ms).

Chronaxie is defined as the shortest effective pulse duration at a pulse amplitude equal to twice the rheobase. The energy consumed by a pulse of which the duration is equal to the chronaxy is minimal.

Chronaxie and rheobase define the electrical properties of a pacing lead. The chronaxie associated with all current lead models range between 0.3 and 0.4 ms, a value which corresponds to the usual nominal pulse width of pacemakers. It is often longer with left ventricular pacing leads.

The pacing threshold is usually lower when measured by gradually lowering instead of increasing the pulse strength, a phenomenon known as the Wedensky effect.

In clinical practice, the measurement of the pacing threshold is of major importance, since the programming of pulse amplitude and duration determines a) the pacing safety margin and 2) the energy consumption of the pulse generator, hence the battery longevity. It is generally recommended to program a 100% safety margin, which corresponds, by convention, to programming a voltage at least twice threshold. This safety margin accounts for the circadian variations in pacing threshold, which, among patients is variably influenced by sleep, food consumption, physical activity, fever, and other factors.

Factors that influence the safety margin

Activity

Acceleration of the heart rate lowers the pacing threshold. During exercise, it is decreased by catecholamines, while it is decreased by sleep and postprandial state.

Drugs and metabolic disorders

Glucocorticoids, epinephrine, ephedrine and isoproterenol lower the threshold, as opposed to propranolol, verapamil, spironolactone, quinidine, and amiodarone. The class IC antiarrhythmic drugs flecainide and propafenone tend to considerably increase the pacing threshold. Consequently, changes in drug therapy should, theoretically, prompt its reassessment.

Other factors that increase the pacing threshold include hyperkalemia, hypoxia, hypercapnia, hyperglycemia, acidosis and metabolic alkalosis.

Degree of fibrosis

At the time of implantation, the direct trauma of the electrode on the endocardium creates a lesion current and a transient rise in threshold lasting a few minutes. Before the introduction of steroid-eluting leads, a rise in capture threshold was often observed within the first 6 weeks after implantation due the inflammation caused by the electrode-induced trauma. During that period, a high pacing voltage amplitude was programed to guarantee an adequate safety margin. Since the introduction of steroid-eluting leads, the pacing threshold remains stable from the time of implantation, allowing the programing of a nominal 2.5 V amplitude.

Longer term, as a result of a chronic foreign body-type inflammatory reaction, fibrotic tissue develops around the electrode at its contact point with the endocardium, separating the electrode from the excitable myocardial cells. Consequently, the capture threshold tends to rise over time, despite the increased stability offered by state-of-the-art lead systems. This rise requires the programming of higher pulse strengths and, consequently, a shortening of the battery longevity. In this perspective, it is recommended to use an automatic adaptive capture algorithm allowing capture with a pulse strength just above threshold, while constantly verifying its reliability.

Influence of the electrode configuration on capture threshold and lead impedance

The size, shape and constituent of the electrode influence the capture threshold. The current density delivered by the distal electrode should be as high as possible, with a view to lower the threshold. Since the current density is highest at its edges, a spherical electrode is associated with higher capture thresholds than an annular electrode.

From the equation $E = U^2 \times t / Z$, the higher the pacing impedance, the lower the current consumption. The pacing impedance, which reflects the sum of forces impeding the flux of current in an electrical circuit, is determined by 3 ohmic resistances:

- Resistance of the conductor, which must be as low as possible, since the current expended to overcome this resistance is lost and dissipated in heat;
- Resistance of the electrode, which must be as high as possible, with a view to lower the current consumption and prolong the battery life. The smaller the radius of the electrode, the higher the electrode resistance, increasing the current density and lowering the capture threshold;
- The polarization impedance, which must be the lowest possible.

A porous and broad microscopic surface covers the electrode in order to 1) maintain a small radius of curvature and thereby increase its resistance, and 2) lower the polarization impedance.

Influence of polarity

A cathodal pulse is associated with a lower threshold than an anodal pulse. Cathodal stimulation narrows the transmembrane potential difference among cardiomyocytes, whereas anodal stimulation causes hyperpolarization, followed by depolarization, with an increase in the quantity of energy needed. Furthermore, the refractory periods are shorter with anodal than with cathodal stimulation, which is associated with a higher theoretical risk of arrhythmogenesis, particularly in vulnerable circumstances, such as ischemia and hypoxia.

The anode of a pacing lead is theoretically floating, thus associated with a very low risk of anodal stimulation, although this is observed when the anode touches the wall and the pacing amplitude is high. Thus, in the majority of cases, bipolar stimulation corresponds to cathodal stimulation.

The unipolar is generally lower than the bipolar pacing threshold.

Atrial and ventricular autothreshold

The strength of the pacing pulses in each cavity hinges on their individually programmed amplitude and duration. While these values can be manually programmed, the “Capture Management” function can be applied to manage the pacing outputs in the atrium and ventricle. This function presumes that the device is able to recognize the efficacy versus inefficacy of a given pulse output amplitude.

At programmable time intervals (e.g. at 1 a.m.), the pulse generator measures the capture threshold to determine the lowest pulse amplitude, combined with the shortest duration, which consistently captures the myocardium. When verifying the capture threshold, the pulse generator prepares for a search, carries out the search and measures the threshold. Over time, these measurements are used to construct a curve of its trend.

The follow-up measurements of the capture threshold are scheduled when no other pending features have a higher priority, starting with a device interrogation to determine whether some programmed settings might interfere with its search. For example, the permanently programmed pulse amplitude or duration may not exceed the 5-V or 1-ms limits, respectively, in each of the right heart cavity. In case of unsuccessful measurement, no further attempt to find a capture threshold is scheduled until the following day.

During the acute phase, i.e. the period of lead maturation following its implantation, the pacing output may be adjusted, though not below the nominal 3.5 V or 0.4 ms, respectively, or below the last manually programmed output settings.

Right ventricular capture management operation

Right ventricular (RV) capture management (CM) is available when the device operates in DDD(R), DDI(R), MVP [AAI(R)<=>DDD(R)] or VVI(R) modes. If MVP is the programmed pacing mode, the pacemaker functions temporarily to DDD (R) mode during the search of capture threshold. RVCM can only be launched at rest during a stable cardiac rhythm. The device performs a search for the RV pacing threshold amplitude at a fixed pulse duration of 0.4 ms. RVCM varies the strength of the pacing pulse to find the lowest amplitude that consistently captures the RV myocardium. The device confirms the capture when it senses a signal in response to the test pulse.

The search for the capture threshold begins at a test amplitude 0.125 V below the last measured value. In absence of prior search, the first test amplitude is 0.75 V, which is then decreased in 0.125-V steps until a test amplitude is classified as below the pacing threshold. The pulse strength is then increased in 0.125-V steps until a same test amplitude has been classified as above the pacing threshold 3 times consecutively, defining the RV capture threshold. A backup pulse is systematically delivered 100 ms after each test, whether or not the test pulse captured the myocardium. The test pulse is delivered at the programmed amplitude and a duration of 1.0 ms.

When RVCM is set on Adaptive, the device automatically adjusts the pacing output to guarantee a capture with a high enough safety margin. When set on Monitor, no adjustment occurs and the data collection is limited to the trend of the pacing threshold. The target amplitude relies on the programmed settings for the “RV Amplitude Safety Margin” and the “RV Minimum Adapted Amplitude” parameters. After a successful search of the capture threshold, the device calculates a target amplitude by multiplying the programmed RV Amplitude Safety Margin by the threshold amplitude measured at a pulse duration of 0.4 ms.

This adaptation can only be accomplished in a range of outputs defined by a programmable inferior limit (Minimum Adapted Amplitude parameter) and a superior threshold limit of 5.0 V and 1.0 ms. The minimum pulse duration for the management of the ventricular threshold is 0.4 ms.

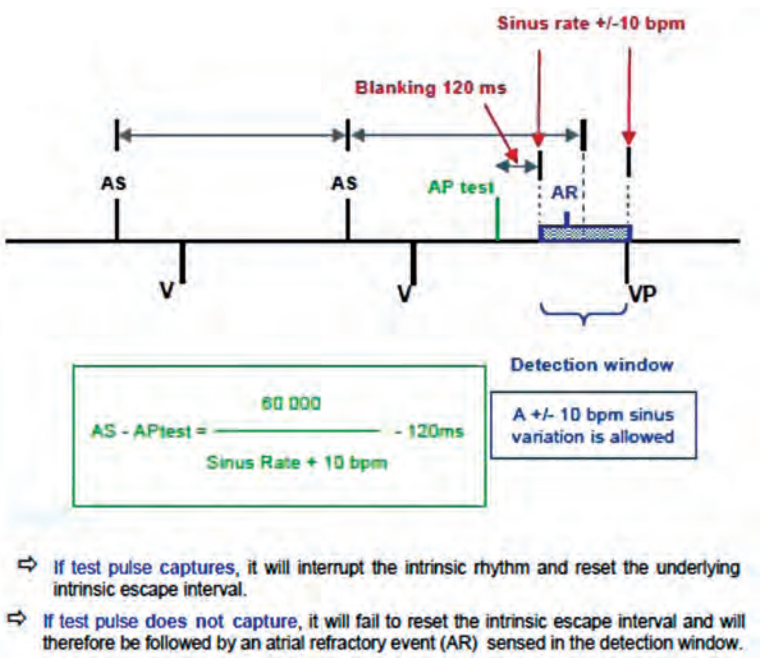
Atrial capture management

Atrial capture management (ACM) is available when the pacemaker operates in DDD or DDD(R) and the MVP [AAI(R)<=>DDD(R)] modes. If the programmed pacing mode is MVP, the device switches temporarily to DDD(R) mode for the duration of the pacing threshold search.

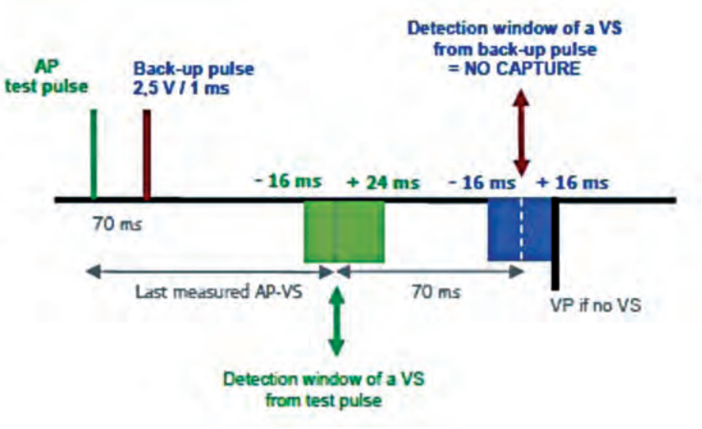
Before the launch of a pacing threshold search, the pacemaker examines whether the patient is being paced or whether it is sensing a slow heart rate. A slow heart rate is desirable during the search of a pacing threshold, to lower the risk of competition between forced pacing and rapid intrinsic rhythms. An atrial capture threshold search is carried out when a stable atrial rhythm has been observed for 8 paced cycles and the sensor-indicated rate is slower than the AQ rate (sensor rate).

The pacemaker searches for the pacing threshold in a series of support cycles followed by a pacing test at a slightly faster rate. Beginning at an output 0.125V below the last measurement (or 0.75 V in absence of previous search), the amplitude is lowered in 0.125 V/ 0.4 ms steps until the device senses loss of capture. ACM monitors the synchronization of the sensed P and R waves (instead of an evoked response) to determine the occurrence of capture.

ACM automatically selects one of the following 2 methods to evaluate atrial capture based on the patient's rhythm at the time of the pacing threshold search:
1) if the patient is in normal and stable sinus rhythm, the device chooses the Atrial Chamber Reset (ACR) method, or 2) if not, it selects the AV Conduction (AVC) method. The ACR method, which requires a stable sinus rhythm, evaluates capture by observing the intrinsic rhythm response to the test atrial pulse. If the latter fails to capture, the sinus node is not reset and an atrial event that follows the test pulse occurs within the atrial refractory period. In absence of atrial event sensed in the refractory period during the AV delay, ACR determines that pacing has captured the myocardium.



The AVC method is applied when stable 1:1 AV conduction is observed during atrial pacing. The atrial pacing rate increases by 15 bpm (without, however, exceeding 101 bpm) and the AV delay is extended in an attempt to obtain a stable AP-VS rhythm. AVC evaluates capture by observing the conducted ventricular response to the test atrial pulse. Each atrial stimulus is followed by a backup pulse at a programed amplitude and 1.0 ms duration to maintain a stable rhythm for the entire duration of the test. When a conducted ventricular event is sensed at approximately the anticipated AP-VS interval in response to the test atrial pulse, AVC determines that pacing has captured the myocardium.



A pacing threshold search begins at a test amplitude 0.125 V below the last measurement. In absence of such, a new search begins at an amplitude of 0.75 V. The device keeps lowering the pulse strength in 0.125 V steps until it reaches a test amplitude that is below the capture threshold. The test pulse is then increased in 0.125 V steps until a same test amplitude has been classified as above the pacing threshold 3 times consecutively, defining the RA capture threshold. The target amplitude is based on the programmed settings for the Atrial Amplitude Safety Margin and the Atrial Minimum Adapted Amplitude parameters.

Capture Management does not program atrial outputs >5.0 V or 1.0 ms. If the patient needs a higher pacing output, the amplitude and pulse width must be programmed manually.

Sensing

Sensing, or sensitivity, expressed in millivolts (mV) defines the ability of the cardiac pacemaker to correctly detect spontaneous cardiac events.

The devices are equipped with entrance filters to allow the specific sensing of P waves in the atrium and R waves in the ventricle, based on the analysis of 3 characteristics of these electrical signals, including the frequency spectrum, slope and amplitude.

The proper programming of the sensing level should allow the detection of all spontaneous cardiac events occurring in the chamber containing the lead, and should reject events of other origins, such as crosstalk from another chamber, myopotentials, or distant interference.

Compared with unipolar, the programming of bipolar sensing increases the specificity by limiting the likelihood of extracardiac signal sensing or crosstalk, and allows the programming of a high sensitivity (0.3 – 0.5 mV in the atrium, 2 to 3 mV in the ventricle). On the other hand, in unipolar configuration, the risk of crosstalk or sensing of extracardiac signals mandates the programming of lower sensing levels (1 to 1.5 mV in the atrium and 4 à 5 mV in the ventricle) with a higher risk of undersensing.

The frequency spectrum

The frequency of a signal is expressed in hertz (Hz), and is the inverse of its periodicity. Pacemakers amplify incoming signals corresponding to the myocardial depolarization signals in a range of frequencies between 10 and 70 Hz. Signals with frequencies above and below that range are filtered and are not sensed or are faintly sensed by the system.

Example: in the ventricular channel, the frequency spectrum of the amplified R wave is between 10 and 30 Hz. On the other hand, T waves, the frequency spectrum of which is <5 Hz, are filtered. Likewise, the frequency of signals originating from the atria that are sensed in the ventricle is usually very low and nearly always filtered.

The frequency spectrum of myopotentials, such as those originating from the pectoral muscle, is superimposed over the P and R wave frequency. In unipolar configuration, the sensing field ranges from the distal electrode of the pacing lead to the pulse generator implanted under the pectoral muscle, with a heightened risk of interference from the sensing of signals of muscular origin during efforts.

Slope

This parameter, expressed in mV/ms, describes the change in cardiac signal amplitude over time. The pacemaker senses the fastest component of the signal, which corresponds to the travel of the depolarization front near the electrode.

If the signal is fragmented, as is sometimes the case with extrasystoles, the slope of its various components is often shallower, increasing the risk of undersensing.

At the time of implantation, the pacing lead(s) should ideally be implanted at a site where the depolarization slope is ≥1 mV/ms in the ventricle and ≥0.5 mV/ms in the atrium. The measurement of the signal slope depends on its conditioning and, in particular, on its filters, which vary depending on the system, whether an external device or the pulse generator that will ultimately be connected. The differences observed can be prominent in both directions. The direct recording of the signal at the time of implantation can nevertheless be useful when searching for the site that yields the largest intrinsic deflection.

The intrinsic deflection of an endocardial signal nearly never coincides with the onset of the surface electrocardiographic signal. For example, the sensing of a ventricular depolarization signal in a patient with complete right bundle branch block is very late. Likewise, in the atrium, the atrial electrogram may be sensed at the end of the surface electrocardiographic P wave.

Signal amplitude

The amplitude of the signal measured by the pacemaker, expressed in mV, corresponds to the amplitude that remains detected by the pacing system after its frequency has been analyzed and slope measured. This parameter is used at the end of the signal conditioning process to determine the level of sensitivity of the system.

The programing of a cardiac pacemaker to a sensitivity of 4 mV means that signals with amplitudes >4 mV can be sensed, after the frequency and slope of the signal have been properly conditioned. All signals with lower amplitudes are rejected.

Increasing the programmed value of sensitivity (e.g. to 12 mV) lowers the sensitivity of the system, since an amplitude >12 mV will be needed for the signal to be detected.

Ultimately, when implanting a pacing lead, attempts must be made to obtain a signal corresponding to the pacemaker's bandwidth, with the fastest intrinsic deflection and the highest amplitude, i.e. ≥5 mV in the ventricle and ≥2 mV in the atrium.

Automatic sensing

The amplitude of the cardiac depolarization signals are not stable and might vary as a function of activity, use of medications, or metabolic changes. In addition, the amplitude of signals associated with atrial or ventricular arrhythmias might differ markedly from normal signals, often considerably smaller, as in the case of atrial fibrillation. Thus, a fixed sensitivity does not assure the detection of all events.

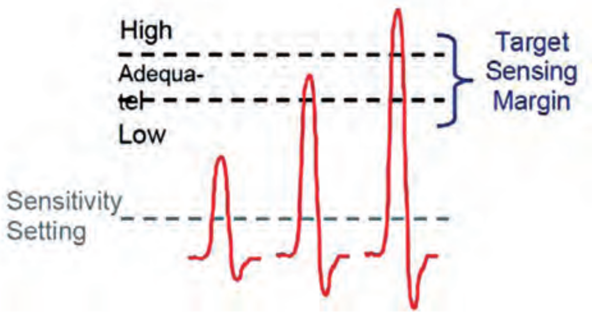
In presence of automatic sensing, the sensitivity level applied at the onset of a sensed event is a percentage (usually 50 to 75%) of the amplitude of the sensed signal. Thereafter, and for a 120 ms duration, the sensitivity level remains stable, before increasing progressively during diastole, until a maximum programmable sensitivity has been reached.

Automatic sensitivity

When the automatic sensitivity function is activated, the pacemaker monitors the amplitude of the sensed signals. Depending on the results, the sensitivity is automatically increased or decreased in order to preserve a sufficient sensing margin, commensurate with the patient's sensed P and R waves. When activated, automatic sensitivity continuously adjusts the sensitivity, as a function of the measured amplitudes, to avoid under- or oversensing.
Depending on the age of the pacemaker series, from Kappa, EnPulse, Sensia, up to the Adapta model, a fixed sensitivity value might be programmable for the entire duration of the cardiac cycle. Alternatively, in Ensura, Advisa and later pacemaker series, as exists in the pulse generator of defibrillators, automatic sensing is adapted to the amplitude of the previous signal, and changes throughout the cardiac cycle.

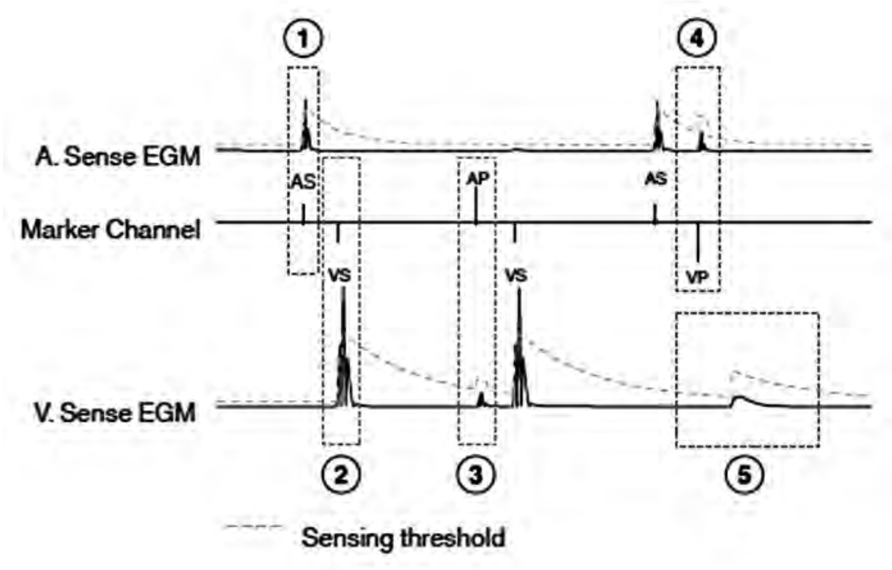
Automatic sensitivity in older pacemaker series, from Kappa, EnPulse, Sensia up to Adapta

The amplitude of each spontaneous P or R wave is measured and compared with a safety interval, which varies according to a) the ambient sensitivity, b) the lead, whether atrial or ventricular, and c) the lead polarity.
The signal amplitude is then classified as large, adequate or low.



In presence of frequent low amplitude signals, the sensitivity is increased by 1 step (smaller numerical value).
In presence of frequent high amplitude signals, the sensitivity is decreased by 1 step (larger numerical value).
A minimum of 17 low amplitudes are needed to increase the sensitivity by 1 step and 36 large amplitudes to decrease it by 1 step.

Automatic sensitivity in recent series (Ensura, Advisa and later series)



After a ventricular sensed event, the threshold value is adjusted to 75% of the R wave, up to a maximum of 8 folds the programmed value, then decreases over 450 ms to reach the programmed sensitivity (for example 0.9 mV).

After a ventricular paced event, the sensitivity to ventricular events remains unchanged and the device is less sensitive to atrial events.

After an atrial sensed event, the threshold value is adjusted to 75% of the wave, up to a maximum of 8 folds the programmed value, then decreases over 200 ms to reach the programmed sensitivity (for example 0.3 mV).

After an atrial paced event, the sensitivity to atrial events remains unchanged and the device is less sensitive to ventricular events.

After the post-pace blanking period, the device is temporarily less sensitive to ventricular events (for example 120 ms).

Case 1: Ventricular Pacing failure

Patient

This 65-year-old man received an Ensura dual chamber pacemaker for treatment of syncope due to high-grade AV conduction defect; he suffered from end-stage renal failure and sustained a syncopal event a few hours before undergoing hemodialysis, 2 months after implantation of the pacemaker.

EGM

The first channel is lead I of the surface ECG with the markers superimposed, the second shows the atrial EGM, the third and fourth show the ventricular EGM, and the last channel is lead III;

1: accurate atrial sensing initiating an AV delay and ventricular pacing (AS-VP); the ventricular EGM and both surface leads show the absence of ventricular capture (no ventricular signal after the pacing stimulus);

2: the spontaneous ventricular event after the preceding P wave is properly sensed (VS);

3: a new atrial sensing-ventricular pacing sequence (AS-VP) is ineffective; the P wave is blocked; the rhythm is consistent with type I (Wenckebach) second degree AV block (progressive prolongation of the PR interval followed by blocked P wave);

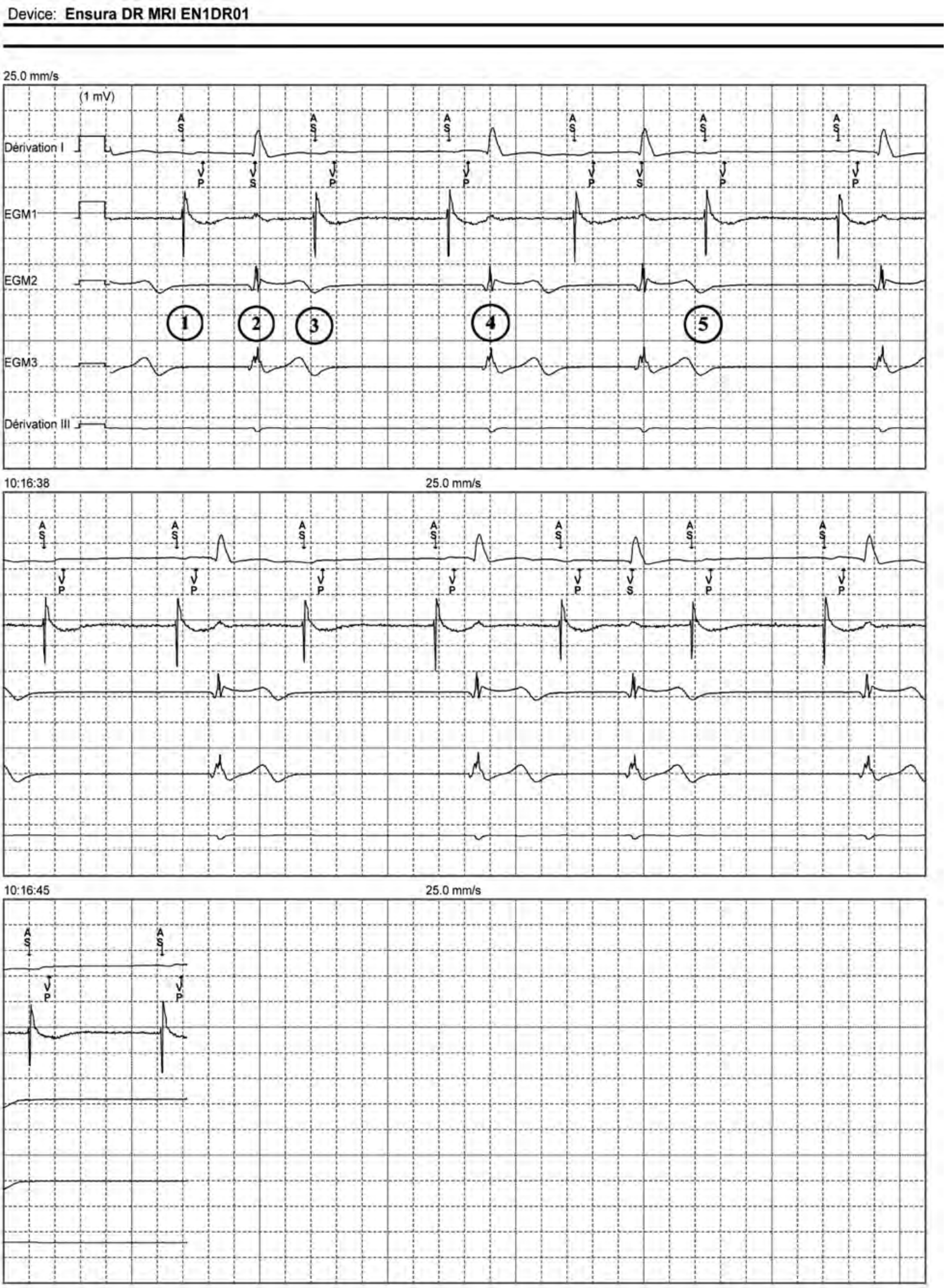
4: ineffective ventricular pacing; the following QRS was not sensed, not due, however, to faulty sensing; instead, the QRS fell in the post-ventricular pacing ventricular blanking period, a period of absolute ventricular refractoriness and, therefore, was not sensed;

5: continuation of missing ventricular capture;

Comments

This pacemaker was programmed at a pacing amplitude of 2.5V / 0.4 ms. In hemodialyzed patients, the status of electrolytes, e.g. sodium, potassium, calcium, and glucose levels change constantly with possible concomitant changes in pacing threshold, requiring a regular monitoring of the pacing output and consequent modifications in order to reliably capture the myocardium. With this in mind, Capture Management is a noteworthy function. When Capture Management is active, the pacemaker automatically monitors the pacing threshold at regular intervals. After it has measured the threshold, the pacemaker sets a target output as a function of a programmable safety margin. This guarantees a reliable capture in patients whose pacing threshold varies widely, without having to permanently program high pacing amplitudes.

In this patient, variations in the ventricular threshold were observed, reaching 3.5 V / 0.4 ms. No lead dislodgement was found on chest X-ray.


Device: Ensura DR MRI EN1DR01
25.0 mm/s
(1 mV)
Dérivation I
EGM1
EGM2
EGM3
Dérivation III
AS
VP
VS
1
2
3
4
5
10:16:38
25.0 mm/s
10:16:45
25.0 mm/s

Case 2: Ventricular Sensing failure

Patient

An 81-year-old asymptomatic woman underwent implantation of an Adapta dual chamber pacemaker for management of atrial disease, which evolved toward well controlled chronic AF; programming in VVIR mode at 60-120 bpm; she was seen on routine follow-up.

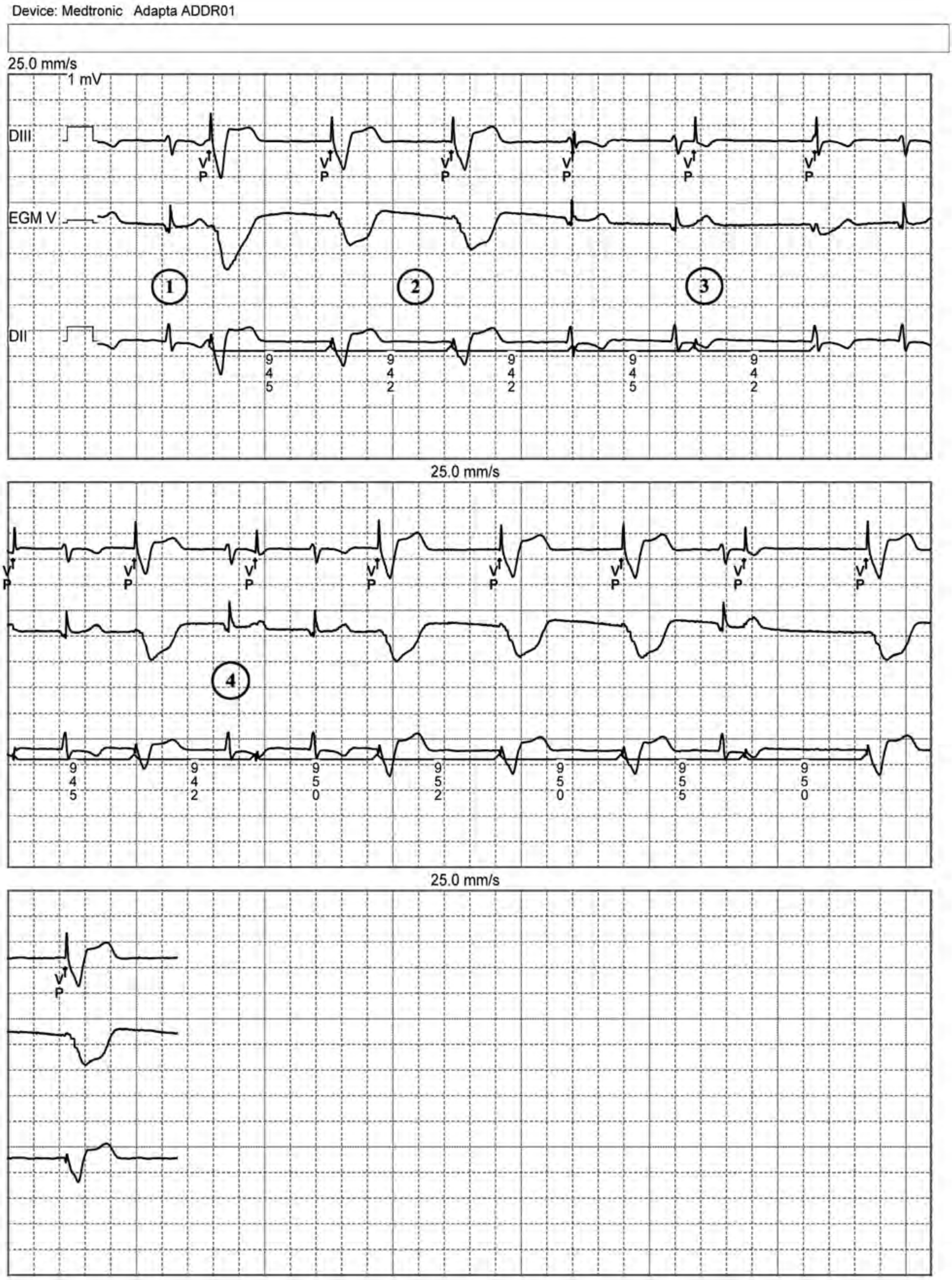
EGM

The first channel is lead III of the surface ECG with the markers superimposed, the second shows the ventricular EGM and the third is lead II with the intervals superimposed;

1: ventricular event not sensed despite appropriate amplitude on the ventricular EGM channel; ventricular pacing in the vulnerable period of the previous QRS and effective ventricular capture;
2: rate responsive ventricular pacing;
3: re-emergence of spontaneous, non-sensed ventricular events with pacing at regular intervals;
4: further pacing in the vulnerable period without capture.

Comments

This tracing shows ventricular undersensing due to faulty programming. The bipolar ventricular EGM measured 3.8 mV, and the device was programmed with a 5-mV sensitivity. In absence of proper sensing, the pacemaker operates as in VOO mode, with no inhibition by the spontaneous ventricular events, as they are not sensed. In these circumstances 1) a large amount of energy is expended unnecessarily (ventricular pacing without capture or with useless and dangerous capture) 2) it creates a risk of proarrhythmia when the ventricle is paced during the vulnerable period. Programming of an appropriate sensitivity rectified the problem.


Device: Medtronic Adapta ADDR01
25.0 mm/s
1 mV
DIII
EGM V
DII
VP
945
942
942
945
942
1
2
3
25.0 mm/s
945
942
950
952
950
955
950
4
25.0 mm/s

Case 3: Atrial Pacing failure

Patient

A 72-year-old man received an Adapta dual chamber pacemaker for management of sinus node dysfunction; programming in AAIR⇔DDDR mode; his symptoms reappeared in the form of near syncope and fatigue.

EGM

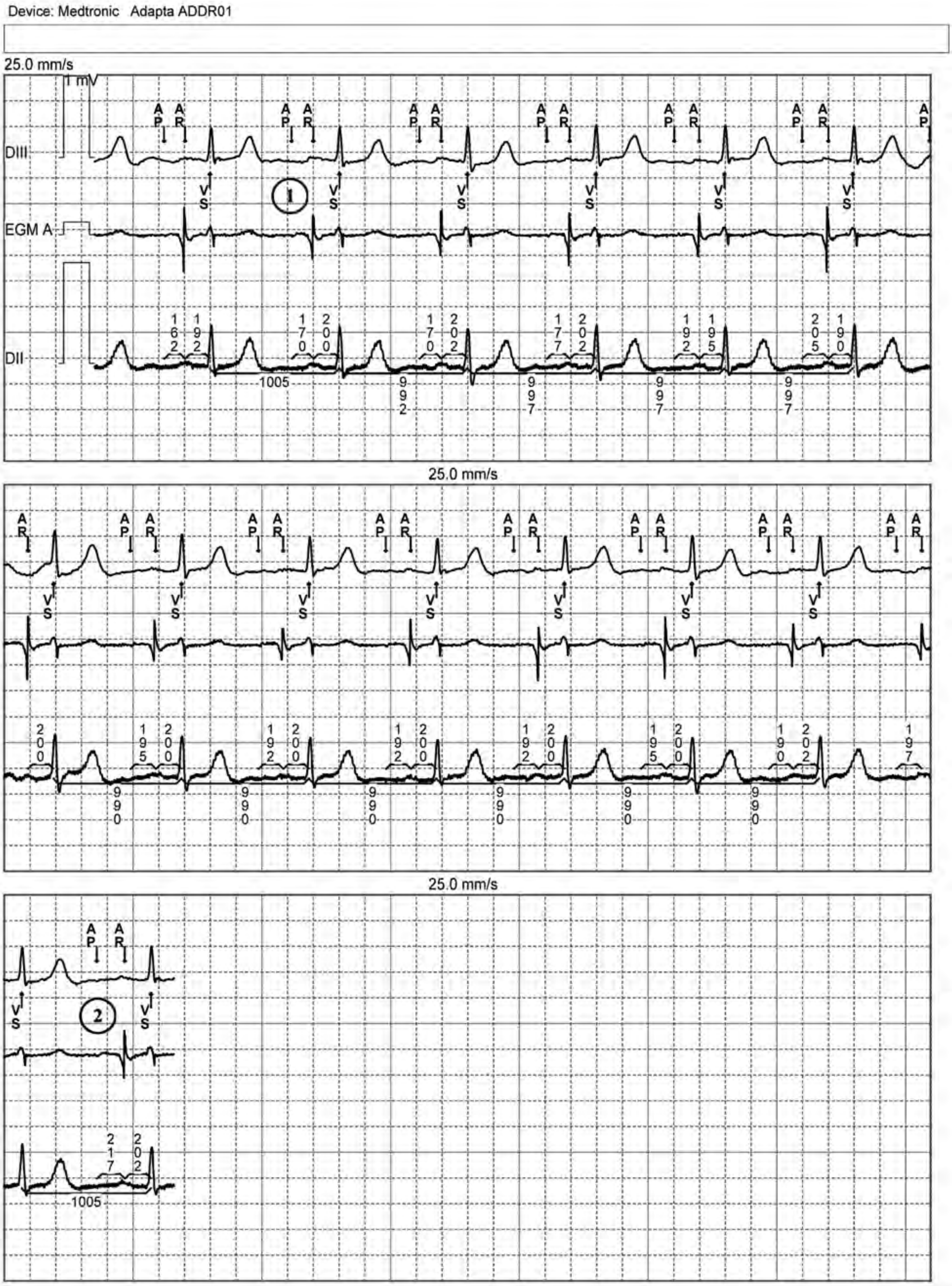
The first channel is lead II of the surface ECG with the markers superimposed, the second shows the atrial EGM and the third is lead II with the intervals superimposed;

1: atrial pacing without capture on the atrial EGM channel; sensing of spontaneous atrial events is labeled AR as they fall in the post-atrial pacing refractory period; spontaneous conduction to the ventricle (VS);

2: continuation of this sequence AP-AR-VS; compared with the beginning of the tracing, the AP-AR interval has gradually increased (from 162 to 217 ms); however, the AR-VS interval has remained fixed (approximately 200 ms), indicating that the spontaneous atrial events are conducted to the ventricle;

Comments

This tracing shows an atrial capture defect. The atrial output amplitude was programmed at 2.5 V / 0.4 ms in this patient. Without apparent cause, the pacing threshold surpassed this value (3 V / 0.4 ms), while sensing remained appropriate (> 2 mV) and the pacing impedance was normal (500 ohms). An increase in the output amplitude to 4 V / 0.4 ms eliminated the dysfunction. In a second stage, the pacing threshold stabilized near 1.6 V / 0.4 ms, allowing a long-term programming at 2.8 / 0.4 ms and guaranteeing acceptable safety margin and energy consumption.


Device: Medtronic Adapta ADDR01
25.0 mm/s
1 mV
DIII
EGM A
DII
AP
AR
VS
1
2
1005
25.0 mm/s
25.0 mm/s

Case 4: Atrial Sensing failure

Patient

A 69-year-old man was in complete AV block after surgical aortic valve replacement; he suffered multiple episodes of postoperative atrial arrhythmias; he underwent pacemaker interrogation 1 month after implantation of a dual chamber pacemaker.

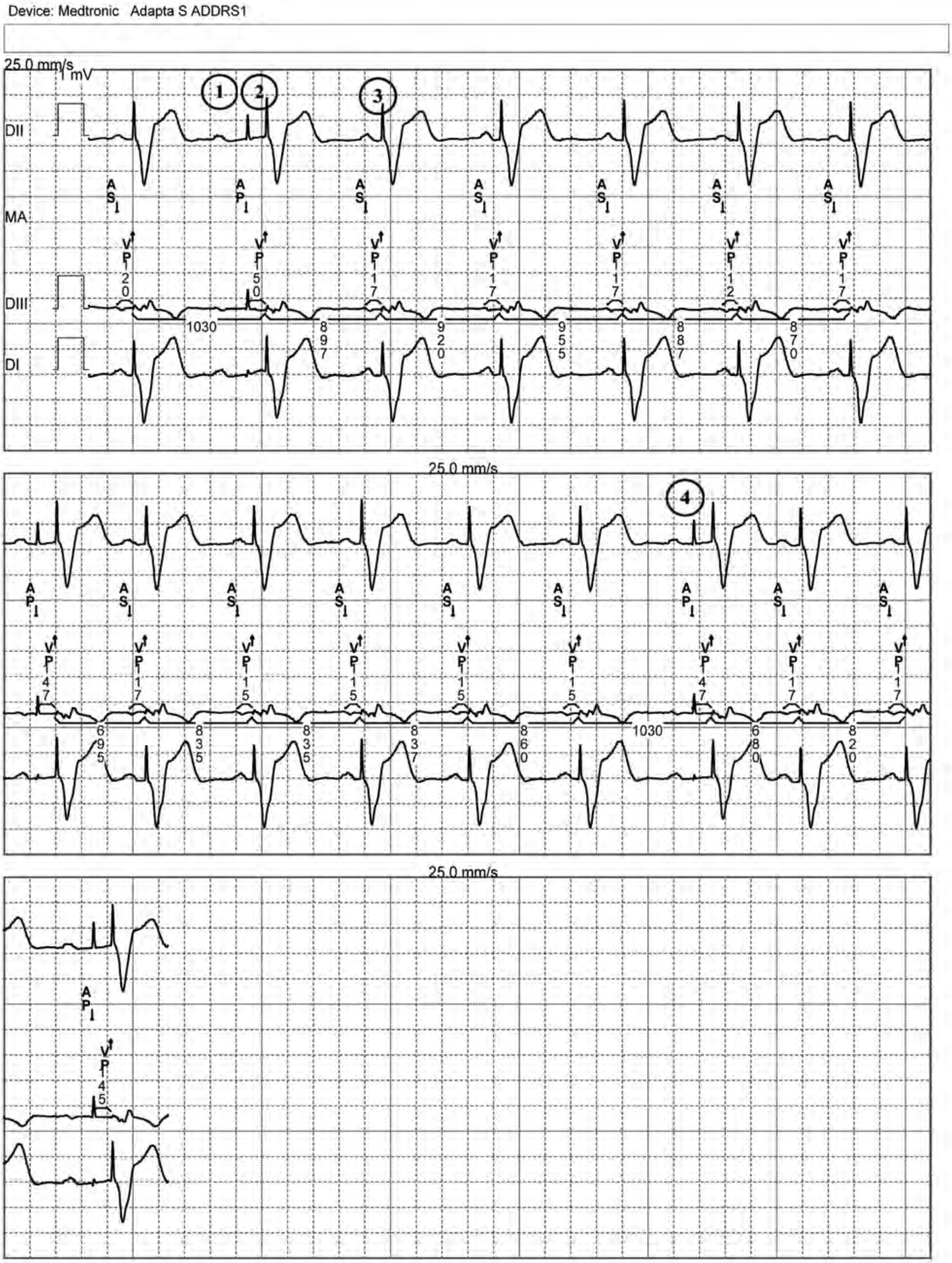
EGM

The first channel is lead II of the surface ECG, the second shows the event markers, the third is lead III with the time intervals superimposed and the fourth is lead I;

1: P waves are visible on the various leads that are not sensed by the device;
2: atrial pacing at the end of the escape interval, in the vulnerable period of the previous non-sensed P wave; ventricular pacing;
3: accurate atrial sensing and ventricular pacing (AS-VP);
4: recurrent atrial undersensing;

Comments

This tracing shows intermittent atrial undersensing. The amplitude of the sensed atrial signal may vary depending on the position of the patient and along the respiratory cycle. In a patient in AV block, a sudden decrease in ventricular pacing rate might be secondary to atrial sensing failure. Besides the absence of a reliable tracking of the P waves during exercise, atrial undersensing may be proarrhythmic if pacing occurs in the atrial vulnerable period, incurring a risk of induction of an atrial arrhythmia. Furthermore, absence of P waves sensing is often followed by ineffective atrial pacing (as in our example), causing a very long P-V interval, which facilitates retrograde conduction and promotes the development of PMT.


Device: Medtronic Adapta S ADDRS1
25.0 mm/s
1mV
DII
MA
DIII
DI
1
2
3
4
1030
25.0 mm/s
25.0 mm/s

Case 5: Dislodgement of atrial lead

Patient

A 78-year-old man received an Adapta dual chamber pacemaker for complete AV block; this tracing was recorded on the morning after the day of device implantation.

EGM

The first channel is lead II of the surface ECG with the event markers superimposed, the second is lead III with the time intervals superimposed and the third is lead I;

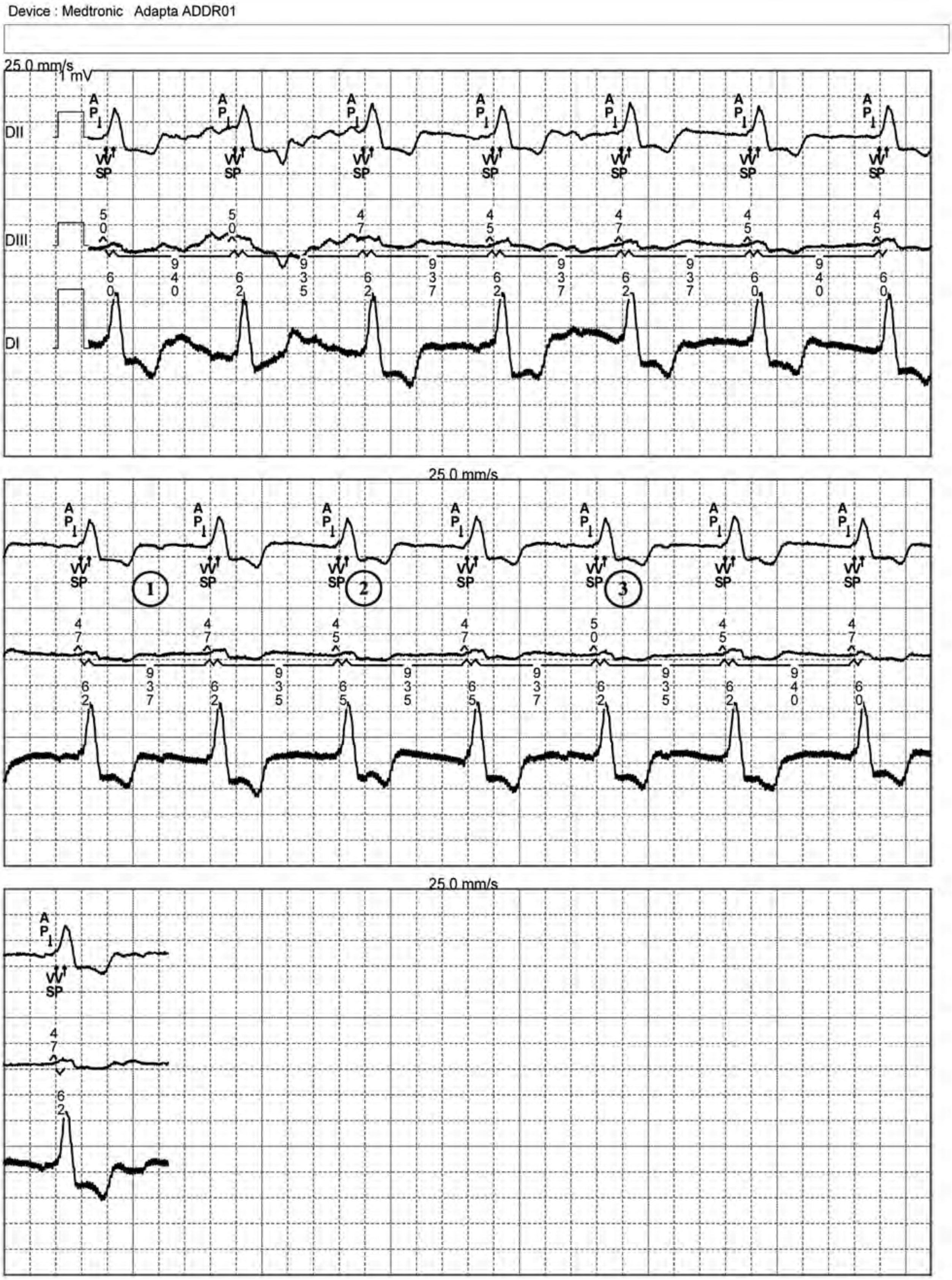
1: non-sensed atrial event;

2: atrial pacing at the end of the escape cycle; the QRS begins after this "atrial" pacing; the atrial lead, in fact, paced the ventricle. The paced ventricle is sensed by the ventricular channel (VS) in the post-atrial pacing safety window. The ventricular channel then delivers a ventricular stimulus (VP) at the end of the safety window, falling in the natural ventricular absolute refractory period;

3: repetition of the AP-VS-VP cycles.

Comments

In this patient, the chest x-ray showed a dislodgement of the atrial lead, with its extremity in the ventricle, explaining the observations made on this tracing, which are similar to what is observed when the atrial and ventricular leads have been inadvertently switched, showing a double spike, with the first spike capturing the ventricle. Unlike on this tracing, however, the second spike usually occurs at the end of the AV delay and is followed by an atrial depolarization.


Device : Medtronic Adapta ADDR01
25.0 mm/s
1 mV
DII
DIII
DI
AP
VP
SP
1
2
3
25.0 mm/s
25.0 mm/s

AV Delay, Refractory Period, PMT

AV delays, refractory periods and management of Pacemaker-induced tachycardia

The atrioventicular delay

The AV delay determines the longest time interval between an atrial event and the programmed delivery of a ventricular pacing pulse. This interval is the electronic equivalent of the PR interval.
The programming of the AV delay intends to ensure optimal mechanical coordination between atrial and ventricular contractions, whether the atrium is sensed or paced. The length of these intervals can be programmed within a wide, fixed or adaptable range and influenced by a large number of algorithms.

Paced AV delay

A paced AV delay is implemented after atrial pacing when the pacemaker operates in DDD, DDI, DVI and DOO modes.
The observed duration of the paced AV delay might differ from the programmed value because of interactions with the following algorithms:
Adaptable AV delay
AV delay+ hysteresis
Ventricular safety pacing
Non-competitive atrial pacing

Sensed AV delay

The sensed AV delay is implemented after a sensed atrial event when the pacemaker functions in atrial synchronized pacing mode (DDD and VDD).
The observed length of the sensed AV delay might differ from the programed value because of interactions with the following algorithms:
Adaptable AV delay
Automatic PVARP
AV delay+ hysteresis
Wenckebach function of the pacemaker during exercise

Setting of the AV delay

The optimal AV delay varies considerably among patients.
The precise programming of the AV delay must allow the maintenance of a constant temporal relationship between left atrium and ventricle and ensure that the left atrial systole has just ended at the onset of left ventricular systole.
The permanent programming of long AV delays to promote spontaneous conduction in patients who are pacemaker non-dependent can now be avoided by implementing the MVP mode. Indeed, a programmed AV delay that is excessively long can be associated with: 1) an enhanced risk of pacemaker-mediated tachycardia (PMT), 2) an enhanced risk of pacing during the vulnerable period of an ventricular extrasystole that was not sensed because it fell during the post-atrial ventricular blanking after atrial pacing, and 3) an adverse hemodynamic effect with fusion of the E and A waves, premature closure of the mitral valve, and valvular regurgitation due to the reopening of the valves at the end of the ventricular diastole.
An excessively short programmed AV delay can be associated with 1) a borderline atrial ejection volume with a loss of the active component, and 2) valve regurgitation in early systole.

Paced versus sensed AV delay

The optimal sensed AV delay is shorter than the optimal paced AV delay for several reasons:

- instead of being sensed at the very onset of the surface P wave, the P wave is sensed at the passage of the atrial depolarization signal under the electrode, which is often delayed with respect of the onset of the P wave on the surface ECG.

- when the P wave is paced, the electro-mechanical delay is longer than when the P wave is of sinus origin; the conduction time between right and left atria is prolonged.

- the difference between sensed and paced AV delays depends on the position of the lead in the right atrium: on average this difference is 30 ms if the lead is in the inter-atrial septum, 50 ms if it is in the appendage, 70 ms if in the high lateral wall, and ≥90 ms if in a low lateral position. These average differences, which must be evaluated and adapted to each individual, are often longer in presence of intra- or interatrial conduction disorders.

- this difference changes minimally with exercise, though tends to shorten under the influence of catecholamines, which shorten interatrial conduction. In presence of major interatrial conduction abnormality, this difference can increase during exercise. Typically, however, this value can remain unchanged within the entire range of programmed changes in rate.

Adaptable AV delay

The PR interval normally shortens with exercise. The adaptation of the AV delay is intended to mimic this physiologic phenomenon; the same adaptation is imposed on the sensed and paced AV delay. The specific characteristics of the adaptable AV delay will be presented in the chapter discussing the settings during exercise.

Refractory periods of single chamber pacemakers

The refractory period is an interval following a paced or sensed event in the chamber containing the pacing or sensing lead, during which the inhibited (SSI) or triggered (SST) pacemaker is not reset.
In a VVI pacemaker, the first part of the refractory period is a programmable, absolutely refractory blanking period. It prevents the resetting of the pacemaker by the sensing of a) post-pacing ventricular potentials, b) the end of the QRS, or c) the T wave. The occurrence of an event during the blanking period is not visible on the marker channels.
The programmed duration of the refractory period is usually between 220 and 350 ms.
The programming of an excessively short refractory period facilitates oversensing, which is reflected by a resetting of the escape interval and a slowing of the pacing rate. The programming of an excessively long refractory period incurs a risk of non-sensing of ventricular premature events. In that case, a stimulus might be delivered at the end of the pacing interval on the T wave of the extrasystole.
In AAI pacemakers, the first part of the refractory period is a programmable blanking period. The refractory period prevents the resetting by an R wave sensed in the atrium (ventriculoatrial cross talk). Its duration must be as long as the AR interval (between the atrial stimulus and the R wave), which is longer than the PR interval, though not inordinately long to ensure atrial sensing up to the maximum sensor-driven rate.

Refractory periods of dual chamber pacemakers

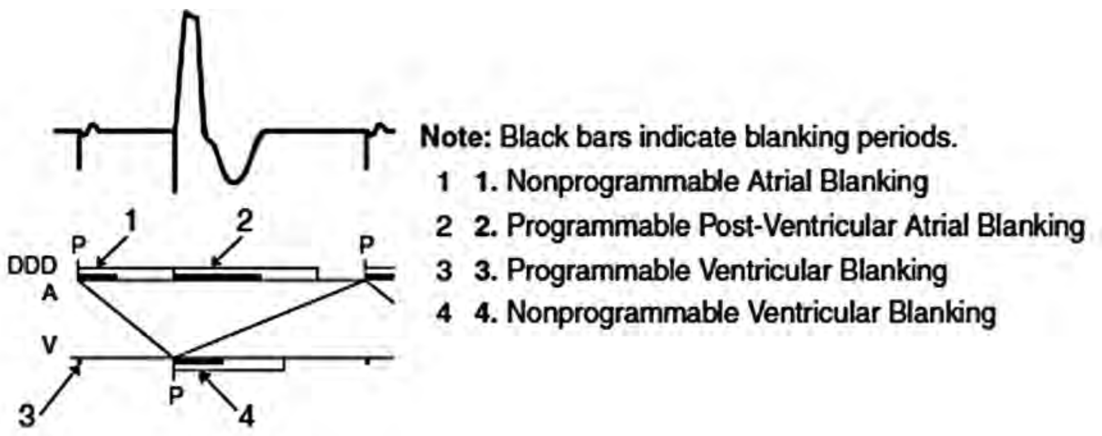
Atrial or ventricular pacing initiates different blanking and refractory periods in the paced chamber as well as in alternate chambers in order to prevent cross talk.

Two types of refractory periods are implemented in DDD mode:

1 : The blanking periods, which completely deactivate sensing for a programmable or non-programmable interval to protect against:

- post-pacing potentials in each chamber;
- atrioventricular or ventriculoatrial crosstalk;

2 : Longer refractory periods, during which sensed events are included in the diagnosis of arrhythmias and in the proper function of various algorithms. In contrast, a spontaneous event sensed during a refractory period does not reset the synchronization interval.
The refractory periods prevent the resetting of the pacemaker by unwanted signals such as retrograde P waves, or electrical interference.
It is noteworthy that in new pacemaker models, the differentiation between a) blanking (absence of sensing and inscription of the signal on the marker chain) and b) refractory period (preserved sensing and presence on the marker chain) is less clear-cut. Thus, an event sensed during blanking might be visible on the marker chain and interfere with the function of various algorithms.



Post atrial pacing ventricular blanking

This programmable ventricular blanking period, triggered by an atrial stimulus, prevents sensing of that stimulus by the ventricle, which would inhibit ventricular pacing and cause ventricular asystole in a pacemaker-dependent patient presenting with complete AV block.
In case of ventricular extrasystole occurring during the post-atrial pacing ventricular blanking, a risk is incurred of ventricular pacing during the vulnerable period. This blanking period is usually programmed between 30 and 40 ms

The safety window

The safety window is a ventricular sensing period that complements the post-atrial ventricular blanking. It is implemented only after atrial pacing. The sensing of a ventricular event after the post-atrial ventricular blanking triggers a ventricular pulse at the end of this safety window. In case of ventricular extrasystole, the pulse is triggered during its refractory period. In case it has sensed an artifact or a late atrial stimulus, ventricular asystole is prevented.

This function is available when the pulse generator operates in DDD, DDI and DVI modes.

The duration of the safety window is 110 ms, or is identical to the paced AV delay if the latter is <110 ms. A short AV delay on the ECG indicates the occurrence of pacing in the safety window. While ventricular safety pacing can be programmed ON or OFF, it is advised to systematically program it ON. The annotations VS and VP are visible on the real-time monitor tracing, on the "frozen" tracings and on the printed tracings.

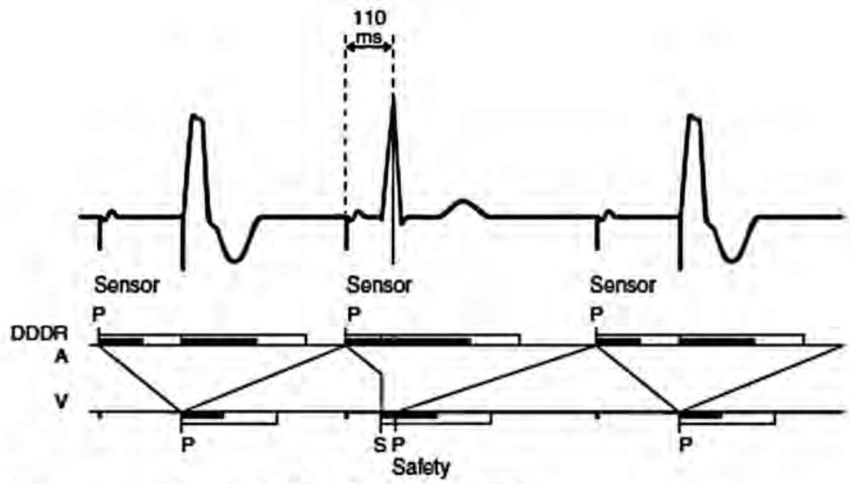
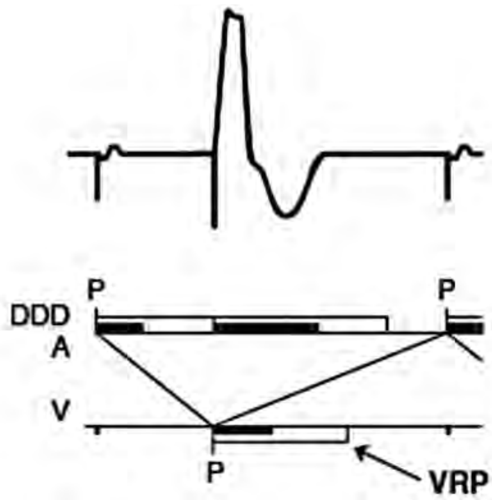


Figure 5-11. Ventricular Safety Pacing (VSP)

The blanking period and the post-ventricular ventricular refractory period

All events sensed or paced in the ventricle trigger a non-programmable ventricular blanking period, the duration of which is dynamically modulated by the pacemaker according to the amplitude and duration of the ventricular stimulus. The dynamic blanking prevents the repetitive sensing of a same event.
The ventricular refractory period (VRP) occurring after a sensed or paced ventricular event prevents sensing of the T wave. A ventricular event sensed during the VRP does not recycle the pacemaker.



Atrial blanking and atrial post-atrial refractory period

The atrial blanking and atrial refractory period (ARP) follow paced or sensed atrial events.

The blanking period and the ARP are used in the AAI or AAT modes.

If the pacemaker is programmed in MVP mode and functions in AAI mode, the ARP is automatically adjusted to 75% of the cardiac cycle, up to a maximum of 600 ms.

Post-ventricular atrial blanking

It is typically an absolute refractory period enforced in the atrium after ventricular sensing and pacing. The PVAB represents the beginning of the PVARP.

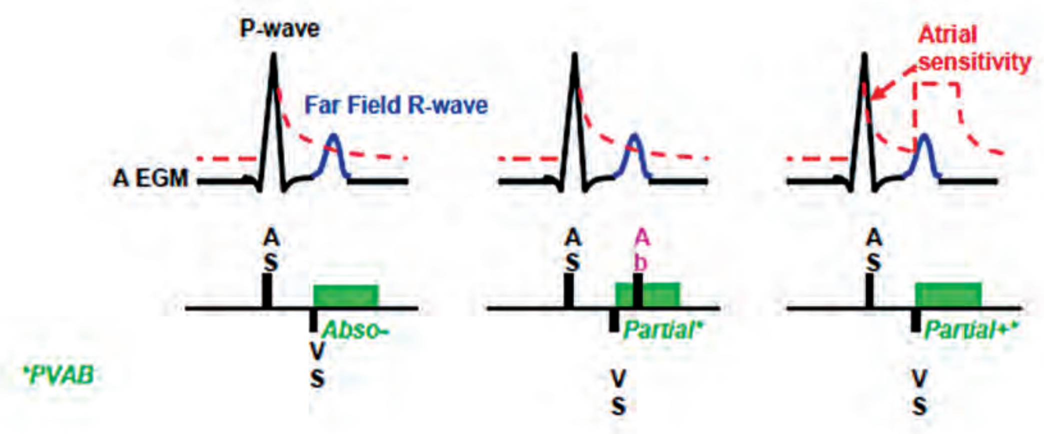
Its role is to prevent the sensing by the atrial chain :
- of the ventricular pacing stimulus
- of the spontaneous or paced QRS.

It operates in DDD, DDI, VDD and VDI modes.

With the Adapta series and older pacemakers, an atrial event falling during that period does not appear on the marker chain and is ignored by the antibradycardia pacing functions such as the AV delay, the adaptable AV delay, non-competitive atrial pacing (NCAP), anti-PMT therapy, the response to ventricular extrasystoles or the stabilization of atrial rhythm.

With more recent pacemakers, such as Ensura or Advisa, which share platforms with defibrillators, the response to an atrial event falling during this period is determined by the interval and the method PVAB. If the PVAB method is set on "absolute", the function is the same as in older pacemakers and the event does not appear on the marker chain. If the PVAB method is set on "partial", an atrial event falling during this period appears on the marker chain and is labeled Ab. This atrial event does not trigger an AV delay, though is counted in the atrial arrhythmia diagnosis. The atrial sensitivity remains unchanged.

If the PVAB method is programmed on "partial+", the function is as described previously, except for an increase in the atrial sensing threshold and decrease in the device sensitivity after the occurrence of a sensed of paced ventricular event.



The post-ventricular atrial refractory period

The post-ventricular atrial refractory period (PVARP) is triggered by ventricular sensing or pacing and is implemented in DDD, DDI and VDD modes.

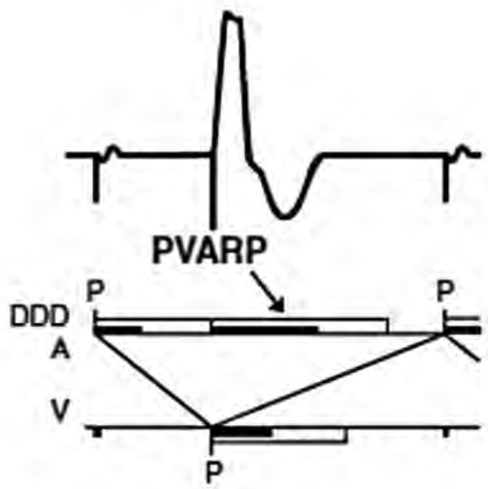
Its main role is to prevent the sensing of retrograde P wave that might trigger a pacemaker mediated tachycardia in the P wave synchronous modes. When the pacemaker is in DDI mode, the PVARP prevents the atrial inhibition by sensing of retrograde P waves.

Its initial component is occupied by the PVAB, which was traditionally absolutely refractory. Past the PVAB, the period is relatively refractory. During the PVARP, intrinsic atrial events might be sensed and identified as refractory (AR) on the event marker channel, though its does not modify the synchronization of the pacing intervals. Thus, an atrial event sensed during this period does not initiate an AV delay. When the pacemaker is in DDD or DDI modes, the expected atrial pacing is not inhibited.

In order to prevent the resetting of ventricular pacing by a retrograde P wave, the PVARP must be programmed at a value longer than the ventriculoatrial conduction time of the patient. The mean retrograde conduction time is between 220 and 280 ms, though might be longer, which requires an adaptation of the PVARP in each individual patient.

An excessively long PVARP might cause the development of 2:1 block during rapid sinus rhythm, when the pacemaker operates in P wave synchronous mode (DDD or VDD). To increase the 2:1 point, the PVARP may be configured to vary as a function of the sensor-indicated rate (sensor-modulated PVARP) or by the mean atrial rate (automatic PVARP). The details of the exercise-dependent settings will be reviewed in another chapter.

While they cannot reset the synchronization interval, the events sensed during the PVARP are used by the pacemaker toward functions that require a knowledge of their periodicity or frequency (mode switch, response to ventricular extrasystoles, adaptable AV delay, automatic PVARP and NCAP). The sensed refractory events are included in the telemetry of the event markers.



Protection against pacemaker-mediated tachycardias

Onset, sustenance and rate of pacemaker-mediated tachycardia

The onset of a PMT requires:

the programming of a P wave synchronous mode (DDD or VDD) intact retrograde conduction loss of AV synchronization; a properly synchronized ventricular and atrial activity blocks retrograde conduction.

Retrograde conduction is present on average in 40% of unselected patients who are paced at rest (up to 80% prevalence in patients paced for sinus node dysfunction, considerably higher than in patients paced for AV block). During exercise, the mean prevalence of retrograde conduction is 75%. This high prevalence justifies an effective protection, which should be systematically programmed. The following events might promote AV dissociation, retrograde conduction and the onset of PMT:

a ventricular extrasystole (the most frequent cause);
an atrial extrasystole with lengthening of the AV delay to respect the programmed upper rate;
an excessively long programmed AV delay; the nodo-hisian tissue has recovered its excitability at the time of ventricular pacing;
an external interference or myopotentials sensed by the atrial chain;
an atrial sensing or pacing defect;
absence of PVARP extension after removal of a magnet, or exit from fallback upon 1:1 AV re-association;
application and removal of magnet;
VDD mode programming in a patient in sinus rhythm at a rate slower than the programmed back-up rate;

PMT is a repetitive sequence in which the pacemaker responds to each retrograde P wave by pacing the ventricle at a rapid rate, which, in turn, produces a retrograde P wave. This cycle repeats itself indefinitely unless interrupted by retrograde block or by the intervention of a specific pacemaker algorithm.
A long-lasting PMT may be poorly tolerated, with symptoms ranging from ill feeling or palpitations to cardiac decompensation in patients suffering from underlying heart disease.

The rate of PMT depends on:

the retrograde conduction time,
the programmed upper rate,
the existing AV delay.

If the retrograde conduction time + the AV delay (at the upper rate) is shorter than the shortest pacing cycle (60,000/upper rate), the rate of the PMT is equal to the programmed upper rate, the AV delay being prolonged with each cycle.

If the retrograde conduction time + the AV delay (at the rate of the PMT) is longer than the shortest pacing cycle (60,000/upper rate), the rate of the PMT is slower than the programmed upper rate and equal to 60,000/(retrograde conduction time + AV delay), and the AV delay is that programmed at the ongoing rate. This hypothesis is observed in approximately 35% of cases.

Prevention of onset of pacemaker-mediated tachycardia

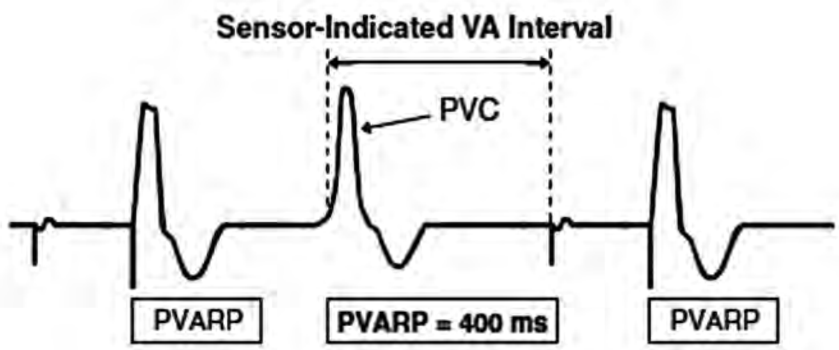
Several measures can help preventing PMT, including:

- the programming of a mode such as DDI which prevents the onset of PMT. It is a pacing mode, which might not be suitable for some patients (absence of ventricular pacing synchronized with sensed P waves).

- the programming of a PVARP longer than the retrograde conduction time, which can be measured at the time of implantation. One must keep in mind, however, that the programming of an excessively long PVARP might cause intolerable 2: 1 AV block during exercise. The programming of a PVARP, or adaptable AV delay, or both, can increase the exercise capacity. A PVARP programmed at 300 ms prevents the development of PMT in a majority of patients.

- avoidance of all instances that might promote a loss of AV synchrony.
- programming of short instead of long AV delays
- program a sufficient safety margin to ensure proper and permanent sensing and pacing
- program bipolar atrial sensing to prevent the sensing of myopotentials or outside interferences
- automatically lengthen the PVARP upon magnet removal

- the response to premature ventricular complexes (PVC) prevents the tracking of retrograde P waves originating from PVC. The pacemaker defines PVC as any sensed ventricular event that follows another paced, refractory or sensed ventricular event in absence of interim atrial event. When the PVC response is ON, a PVC initiates a 400-ms PVARP if its programmed value or the on-going value is <400 ms.



Diagnosis of pacemaker-mediated tachycardia by the pacemaker

The anti-PMT intervention is available when the device functions in DDD, VDD, or MVP mode. With MVP mode, the anti-PMT intervention functions only in DDD mode.
The pacemaker diagnoses a PMT when it detects 8 consecutive VA intervals which fulfill all these conditions:

- VA interval <400 ms
- VA interval begins with a paced ventricular event
- VA interval ends with a sensed atrial event

Using the activity sensor-indicated rate, the pacemaker verifies that the eight consecutive VA intervals are tracked retrograde P waves instead of an intrinsic accelerated atrial rhythm.

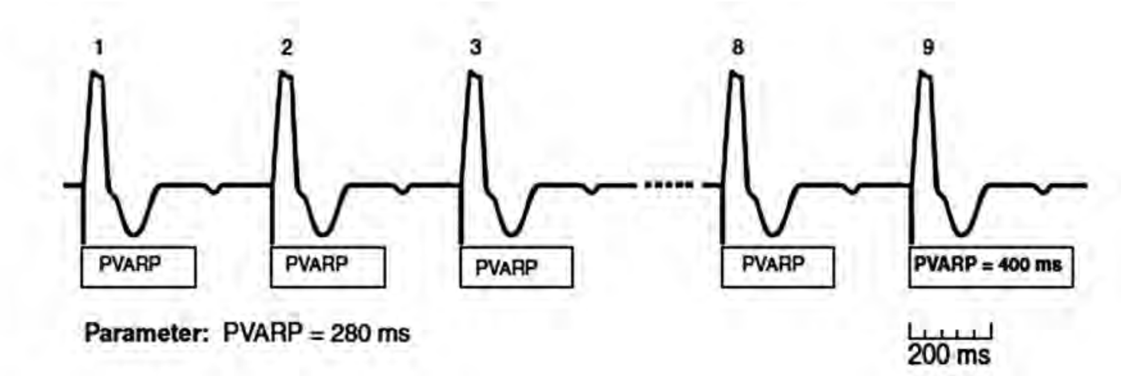
- if the sensor-indicated rate is below or equal to the AQ rate, an episode of PMT as defined by the device is confirmed and therapy is delivered.
- if the sensor-indicated rate is > than the AQ rate, rapid sinus rhythm is diagnosed and no therapy is delivered, and,
- the pacemaker continues its monitoring of series of eight consecutive VA intervals along with the sensor-indicated rate.

Anti-pacemaker-mediated tachycardia therapy

This algorithm interrupts PMT by lengthening the PVARP and sensing the next retrograde atrial event in the refractory period. This refractory event does not synchronize ventricular pacing and the tachycardia is interrupted.

When a PMT is detected, a 400-ms PVARP is introduced after the 9th paced ventricular event. If a PMT is ongoing, the extended PVARP ensures that the next sensed atrial event occurring within a 400-ms delay will be refractory.

Sinus tachycardia might prompt an anti-PMT intervention, causing a single P wave during the PVARP, consequently not tracked by the pacemaker.



Following an intervention, the anti-PMT function is suspended automatically for 90 sec, preventing repetitive and unnecessary interventions in cases of rapid and stable intrinsic atrial rates.

The anti-PMT intervention function interacts with other pacemaker functions:

- atrial non-competitive pacing (NCAP) is automatically activated for one cycle after the 9th ventricular paced event of a PMT episode. The function NCAP can shorten the next paced AV delay to stabilize the ventricular rate.
- if mode switch is programmed ON, the anti- PMT intervention is temporarily deactivated in case the pacemaker switches to the atrial non-tracking mode. It is reactivated as soon as it has returned to atrial tracking.

Case 1: Far-field sensing by the atrial channel

Patient

This 74-year-old man received an Ensura DR dual chamber pacemaker for complete AV block after aortic valve surgery; the atrial lead was implanted in the right atrial appendage and the ventricular lead was placed in the high septum; he was asymptomatic and was seen in follow-up 3 months after implantation of the pacing system.

EGM

Tracing 1a: tracing recorded upon arrival; programmed in DDDR mode; the first channel is lead I of the surface ECG upon which the markers are superimposed, the second channel is the atrial EGM, the third is lead II and the last channel is lead III;

1: sequences AP-VP-AR with fixed VP-AR intervals; atrial pacing appears effective; the atrial EGM show atrial depolarization after each AP, confirming that the atrium was effectively captured; ventricular capture is also confirmed; behind each VP, the atrial EGM shows a signal of low amplitude, which probably represents far-field sensing of the end of the ventricular signal by the atrial channel;

Tracing 1b: change in programming with prolongation of the post-ventricular atrial blanking;

2: same tracing and same programming as the preceding figure;
3: change in programming with prolongation of blanking (successful programming);
4: the atrial signal sensed behind each ventricular paced event is identical, though is now sensed in the post-ventricular atrial blanking (fixed VP-Ab intervals);

Tracing 1c: change in programming with lower atrial sensitivity;

5: same tracing and same programming as the preceding figure;
6: change in programming with lower atrial sensitivity;
7: elimination of far-field sensing.

Comments

The post-ventricular atrial blanking is the first phase of the post-ventricular atrial refractory period. As illustrated on this tracing, in a recipient of an Ensura pacemaker, the programmer shows the sensing of atrial events that fall in that blanking period as "Ab" on the marker chain, and includes it in the count of arrhythmias. When an atrial event occurs in the post-ventricular atrial refractory period after blanking, it is identified as AR on the recording of event markers; however, it neither changes the synchronization of the pacing intervals nor initiates an AV delay. This prevents ventricular synchronization to a retrograde P wave that might trigger a PMT.

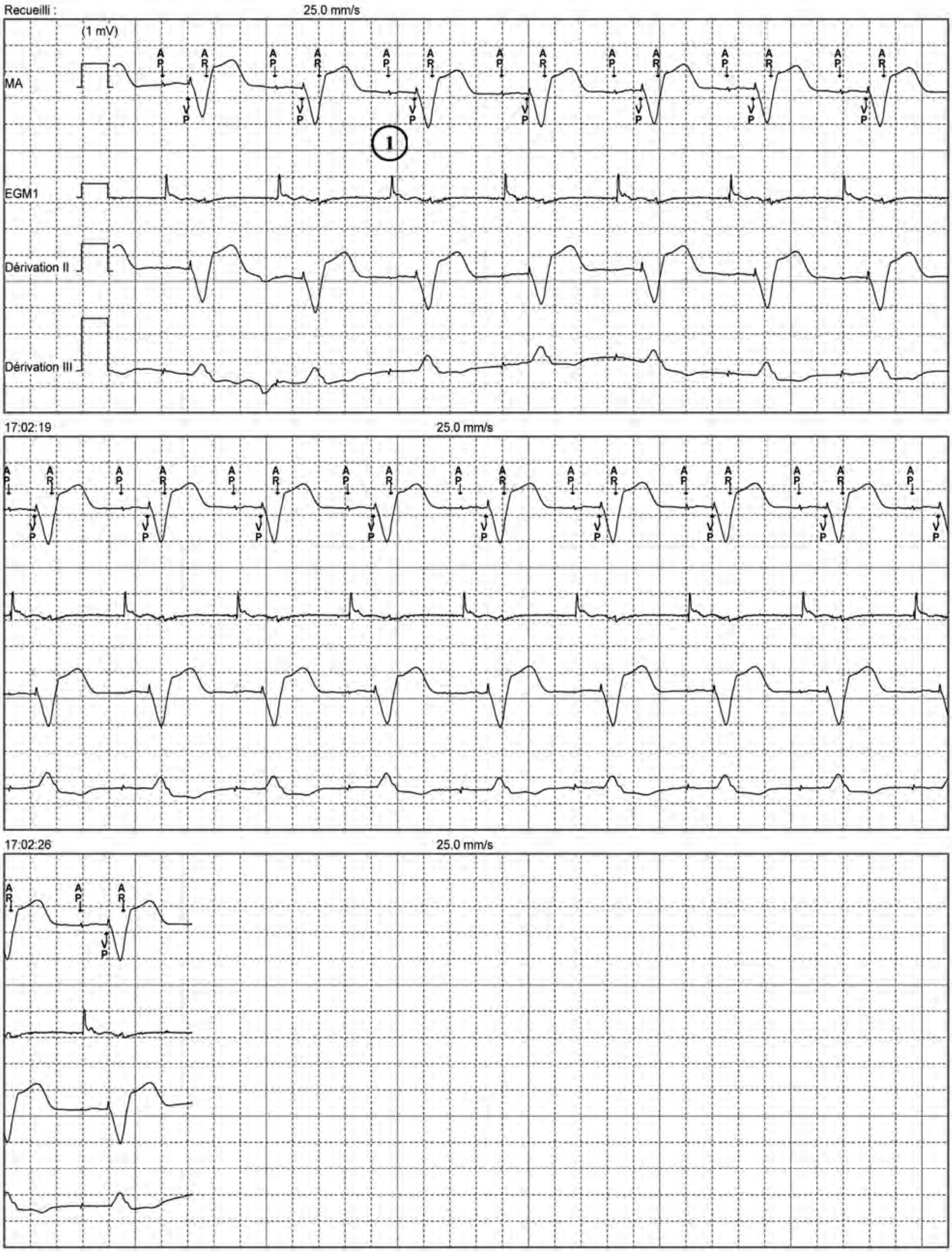
In this patient, the diagnosis of crosstalk is evident; compared with ventricular pacing, the additional sensed atrial signal is of low amplitude and very early. To prevent crosstalk, one might consider 4 measures:

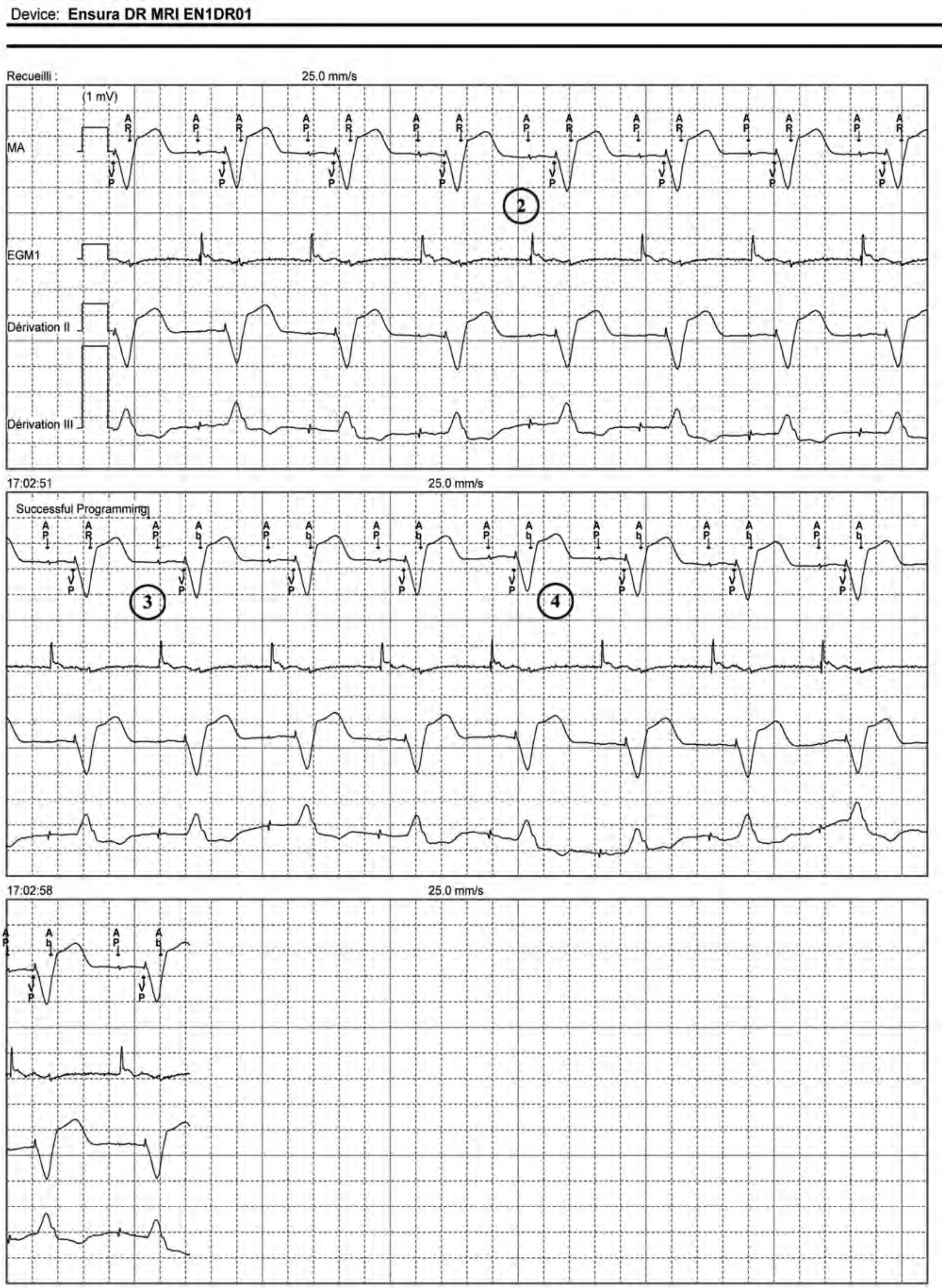
1) a) lower the strength of ventricular pacing, b) program ventricular pacing in bipolar configuration (as was already the case), or c) both; in the majority of cases, however, these changes have little impact on oversensing, since it is the depolarization of the ventricles instead of the ventricular pacing stimulus that is sensed in the atrium.

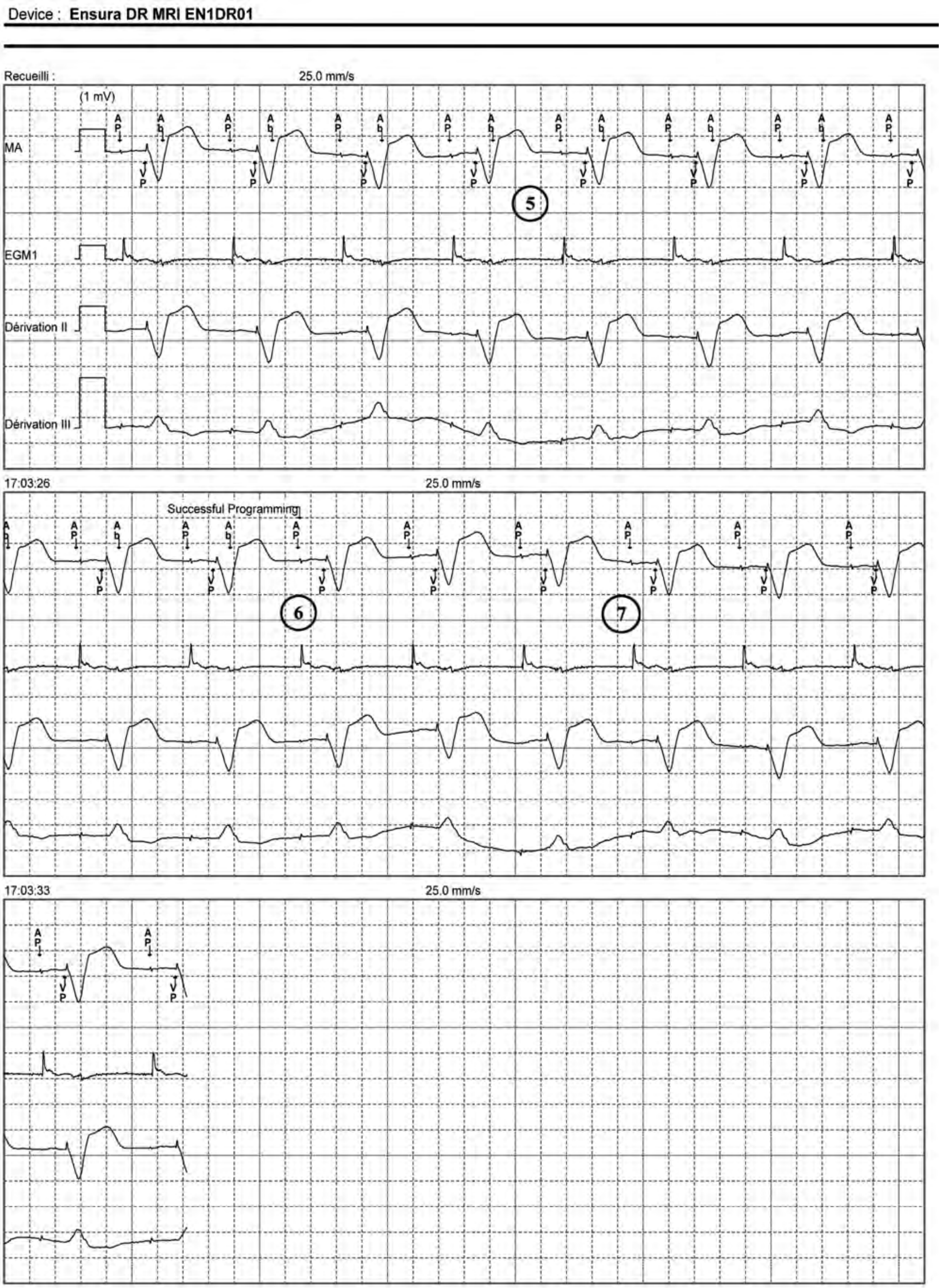
2) program atrial sensing in a bipolar configuration (as was already the case).

3) make the atrial channel less sensitive; a reprogramming to 0.5 mV (instead of 0.3 mV initially) eliminated oversensing. This reprogramming incurred a risk of decreasing the detection of atrial arrhythmias, AF in particular, due to the damping of the atrial signals.

Device: **Ensura DR MRI EN1DR01**




Device: Ensura DR MRI EN1DR01
Recueilli :
25.0 mm/s
(1 mV)
MA
EGM1
Dérivation II
Dérivation III
AR
AP
VP
2
17:02:51
25.0 mm/s
Successful Programming
3
4
17:02:58
25.0 mm/s


Device : **Ensura DR MRI EN1DR01**
Recueilli :
25.0 mm/s
(1 mV)
MA
EGM1
Dérivation II
Dérivation III
5
17:03:26
25.0 mm/s
Successful Programming
6
7
17:03:33
25.0 mm/s

Case 2: Far-field sensing ?

Patient

This 63-year-old man, received an Ensura DR MRI dual chamber pacemaker for management of syncopal events due to complete AV block and degenerative disease of the conduction system; EGMs were recorded at the beginning of his first post-implantation follow-up, with the device programmed in DDD mode.

EGM

The first channel is lead I of the surface ECG upon which the markers are superimposed, the second channel are the atrial EGM, the third and fourth channels are ventricular EGM and the last channel is lead III of the surface ECG;

1: the observations are similar to those made on the previous tracing; AP-VP-Ab sequence; the analysis of the atrial EGM is, however dissimilar, as the atrial capture is not evident;

2: new AP-VP-Ab sequence; the VP-Ab delay is not fixed (longer) compared with the preceding cycle, which is inconsistent with far-field sensing;

3: AP-VP-AR cycle; on the atrial EGM the post-ventricular atrial signal is identical tough the VP-AR delay has lengthened further; the atrial signal is no longer sensed in the blanking period but rather in the post-ventricular atrial refractory period (AR);

4: the VP-atrial signal interval has continued to lengthen, and the atrial signal, now outside of the refractory period is labeled AS; therefore, it initiates an AV delay and a ventricular paced event at the end of the programmed AV delay;

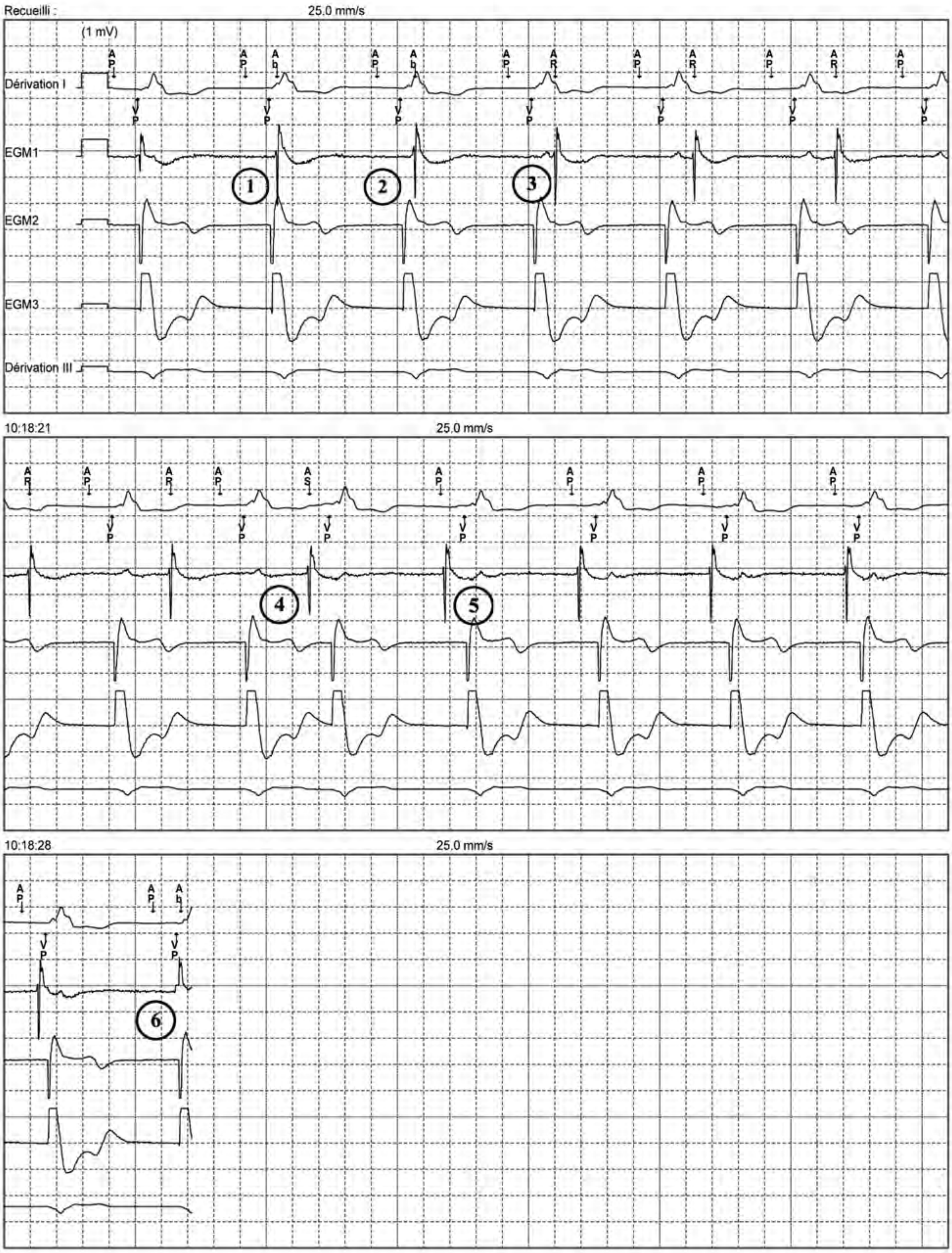
5: a spontaneous atrial signal occurs just after atrial pacing and, since it fell in the post-atrial atrial blanking period, is not sensed by the device;

6: return to sequence no 1;

Comments

This tracing does not illustrate crosstalk rather than loss of atrial capture in a patient presenting with complete AV block and a sinus rate below the programmed backup rate. The patient is in AV and VA block. The tracing shows dissociation between spontaneous atrial events and ventricular pacing. Therefore, this loss of atrial capture does not trigger a PMT. An increase in the output amplitude above the pacing threshold normalized the pacemaker function.

Device : **Ensura DR MRI EN1DR01**



Cases 3: AV crosstalk

Patient

This 62-year-old woman has been dual chamber paced for 11 years; she underwent replacement of the pulse generator 2 months earlier; she complains of dyspnea; these EGMs were recorded.

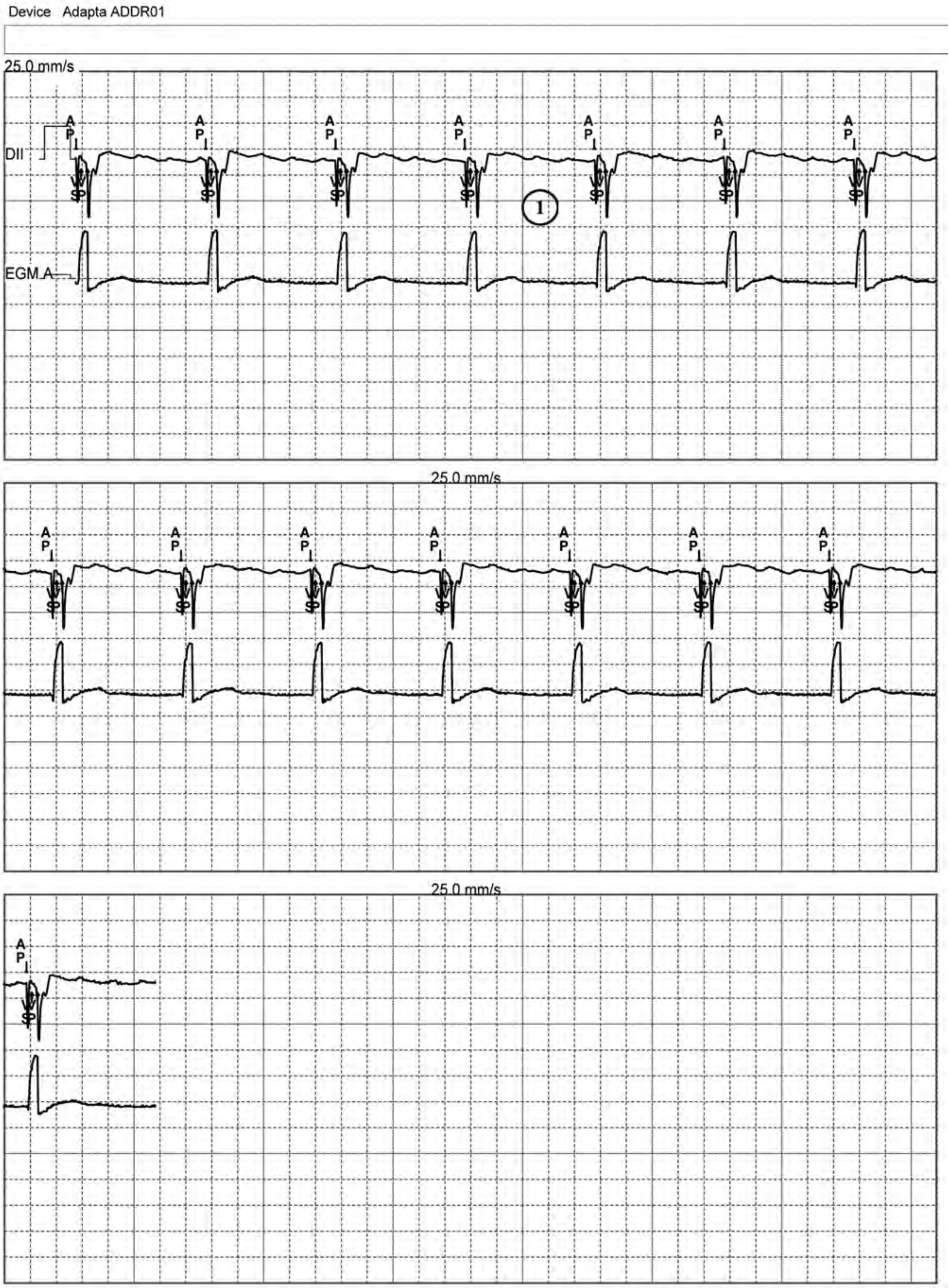
EGM

The first channel is lead II of the surface ECG upon which the markers are superimposed; the second channel shows the atrial EGM;

1: repetition of the cycles with an AP-VS-VP sequence; the atrial and ventricular stimuli are of high amplitude, consistent with the programming of unipolar pacing; the AP-VS and VS-VP intervals are very short; the AP-VP interval lasts 110 ms; the atrial EGM confirms the effectiveness of atrial capture; likewise, while the tracing is of low quality, ventricular capture seems effective;

Comments

This tracing shows AV crosstalk with ventricular pacing in the safety window. Atrial pacing is sensed in the ventricular channel after the post-atrial ventricular blanking in the safety window, which triggers ventricular pacing 110 ms after atrial pacing in this pacemaker-dependent patient; the absence of this protection would have caused asystole. This crosstalk was permanent in this patient. The short AV delay might have been the cause of the dyspnea she complained of since the replacement of her pulse generator, as it was associated with sub-optimal AV synchrony. The end of atrial systole occurred during ventricular systole, resulting in a dual chamber pacemaker syndrome. Pacemaker interrogation explained etiology of the crosstalk, as both bipolar leads were programmed in unipolar configurations for pacing and sensing. To eliminate AV crosstalk, 5 options might be considered:
1) program bipolar atrial pacing; 2) lower the strength of atrial pacing while preserving a safety margin with respect to the capture threshold; 3) program bipolar ventricular sensing; 4) lower the sensitivity of ventricular sensing; 5) lengthen the post-atrial ventricular blanking. In this patient the resetting of bipolar atrial pacing and ventricular sensing resolved the dysfunction.
The safety window, which prevents asystole due to the inappropriate inhibition of ventricular pacing caused by oversensing of the atrial stimulus, must be systematically programmed ON.


Device Adapta ADDR01
25.0 mm/s
DII
EGM A
AP
VS
1
25.0 mm/s
25.0 mm/s

Case 4: Blanking, safety window, AV delay

Patient

This 61-year-old man received a dual chamber pacemaker programmed in DDD mode for management of syncope due to paroxysmal sino-atrial block; he was seen for routine follow-up and the following tracings were recorded.

EGM

The first channel is lead III of the surface ECG upon which the markers are superimposed, the second shows the atrial EGM, and the third is lead II with the markings of the time intervals;

1: accurately sensed AS-VS cycle;

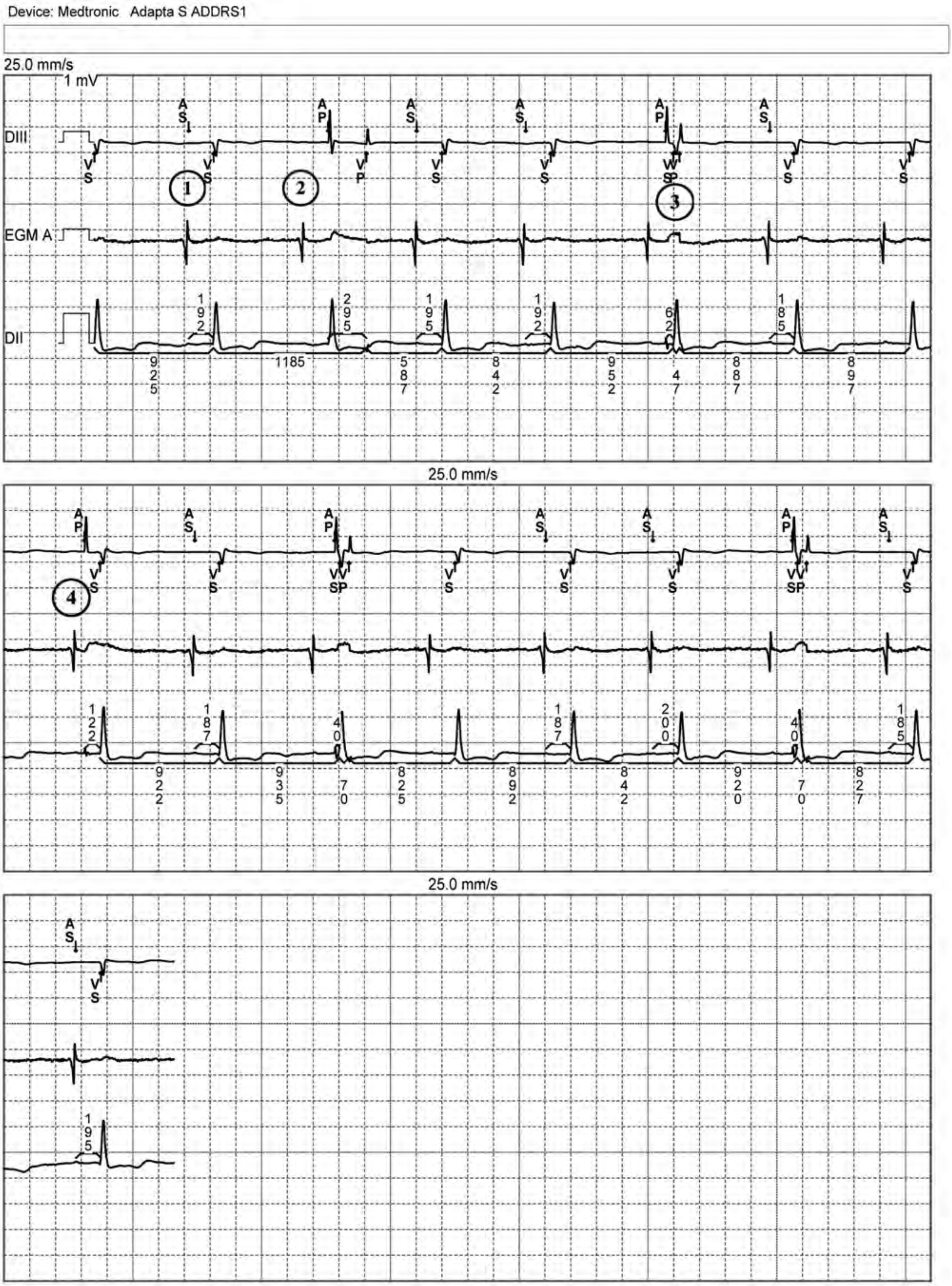
2: atrial undersensing; the atrial EGM channel shows that the atrial signal is not sensed by the pacemaker; in absence of atrial sensing, the atrium is paced (AP) at the end of the escape cycle; the spontaneous QRS originating from the non-sensed atrial event falls just after AP, in the post-atrial pacing ventricular blanking period; therefore, this spontaneous ventricular event is not detected and does not trigger ventricular safety pacing; ventricular pacing is, therefore, triggered at the end of the AV delay, though is ineffective; this paced event is risky, as it falls on the T wave of the preceding spontaneous QRS complex;

3: same sequence: atrial undersensing, atrial pacing and spontaneous ventricular event; this time, the spontaneous ventricular event does not fall in the blanking period rather than in the safety window; consequently, it is sensed and triggers a paced event at the end of the crosstalk safety window, which is ineffective and innocuous, as it falls during the absolute refractory period of the preceding spontaneous ventricular complex;

4: same sequence: atrial undersensing, atrial pacing and spontaneous ventricular event; the latter is neither in the blanking period nor in the safety window, but at the end of the AV delay, i.e. the ventricular alert window, and, therefore, inhibits ventricular pacing;

Comments

This tracing illustrates the occurrence of intermittent atrial undersensing in the absence of other functional abnormalities. It shows the 3 ventricular intervals that follow atrial pacing, i.e. the blanking period, the crosstalk safety window and the alert window in the terminal portion of the AV delay; it shows the pacemaker's response to a ventricular event falling during each of these intervals. The duration of the safety window is not programmable and is fixed at 110 ms. If the blanking period is programmed too short, the risk of detection of the atrial stimulus in the crosstalk safety window is high, constantly forcing ventricular safety pacing. This excessively short AV delay can be hemodynamically deleterious. If the blanking period is programmed too long, a late ventricular extrasystole might not be sensed, creating a high risk of pacing in its vulnerable period, at the end of the AV delay (a ventricular extrasystole falling during the blanking period does not modify the behavior of the pacemaker, which paces at the end of the programmed AV delay). This risk increases with the programming of long blanking periods and long AV delays. An acceptable compromise is usually reached by programming a blanking period between 30 and 40 ms.
In this patient, the actual problem is that of intermittent atrial undersensing, which was solved by reprogramming the atrial sensitivity.


Device: Medtronic Adapta S ADDRS1
25.0 mm/s
1 mV
DIII
EGM A
DII
1185
25.0 mm/s
25.0 mm/s

Case 5: PMT

Patient

This 83-year-old man underwent implantation of an Adapta dual chamber pacemaker for complete AV block; 4 days after his discharge from the hospital, he was seen in the emergency department, complaining of palpitations; this tracing was recorded; pacemaker is programmed to the DDDR mode.

EGM

Tracing 5a: recording upon the patient's arrival; the first channel is lead I of the surface ECG upon which the markers are superimposed, the second channel shows the atrial EGM and the last channel is lead II with the time intervals superimposed;

1: tachycardia at 110 bpm, the programmed maximum rate; repetition of AS-VP cycles with prolongation of the AV delay (210 ms when the programmed AV delay for spontaneous atrial activity is 120 ms) in order to not surpass the programmed maximum rate; this might be sinus tachycardia (unlikely with the patient at rest), a relatively slow atrial tachycardia or a PMT;

Tracing 5b: an initial interrogation reveals that the anti PMT algorithm is OFF (nominal programming); the algorithm was programmed and the EGM recorded;

2: same tracing as earlier;

3: programming of the algorithm;

4: the diagnosis of PMT is made by the device: 8 consecutive cycles with a VA interval <400 ms [340 ms in this patient: 500 ms (interval VP-VP) – 160 ms (AV delay)]; the VA interval begins with a paced ventricular event, the VA interval ends with a sensed atrial event, and the pacing rate = the maximum programmed rate; anti-PMT intervention: prolongation of the post-ventricular atrial refractory period to 400 ms; atrial events occur during this refractory period and ventricular pacing is not triggered;

5: atrial pacing after 300 ms to prevent pacing during the atrial vulnerable period and prevent ineffective atrial pacing when delivered during the absolute, natural, atrial refractory period, and ventricular pacing (AP-VP) with a short AV delay; this short AV delay is also a consequence of non competitive atrial pacing (NCAP), which is automatically activated for 1 cycle after the 9th ventricular paced event of an episode of PMT. This function shortens the next paced AV delay to maintain a stable ventricular rate;

6: interruption of the tachycardia and paced AV rhythm (AP-VP);

Comments

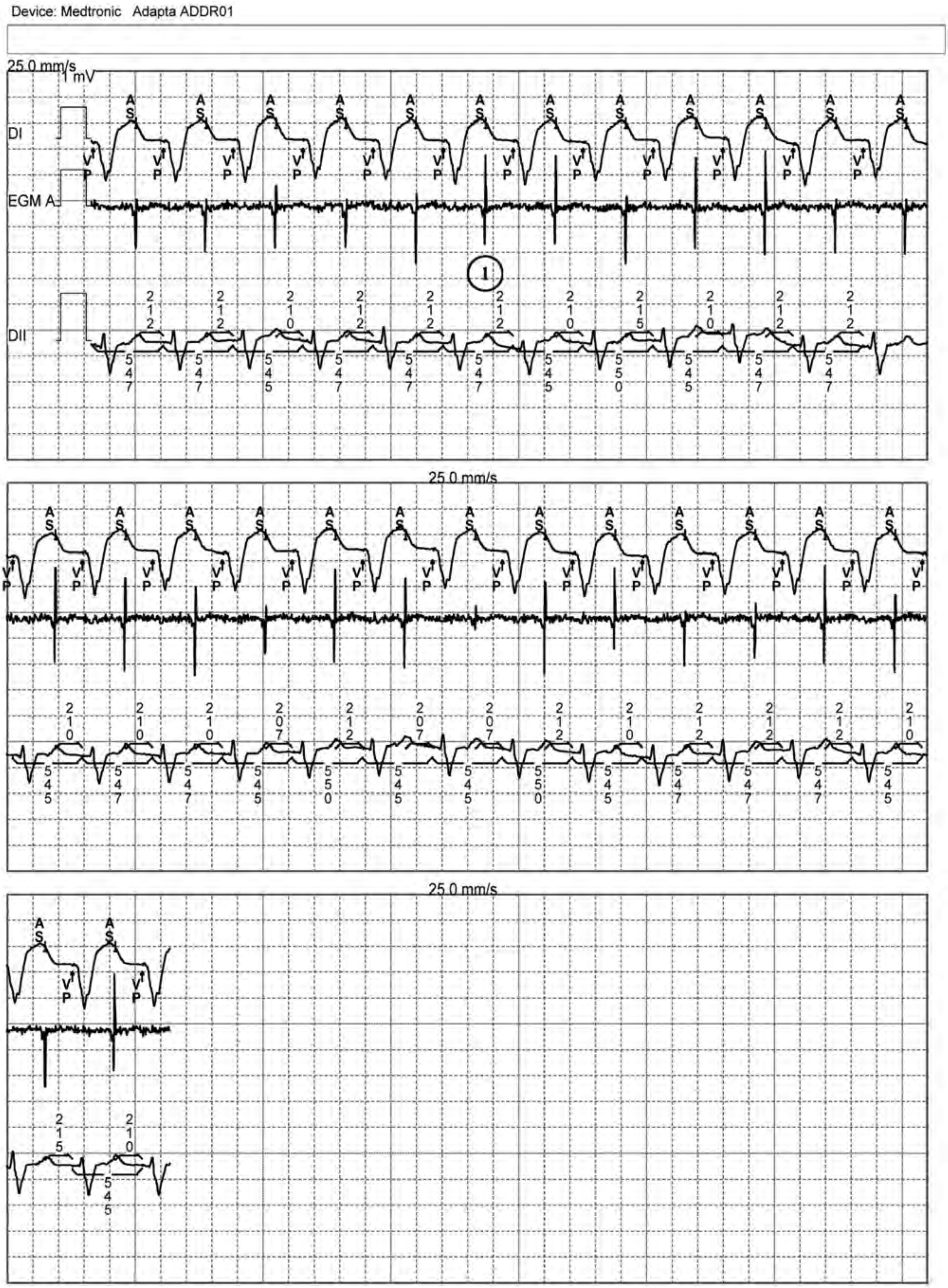
This tracing corresponds to an episode of PMT and highlights some aspects of the Medtronic dual chamber pacemakers function:

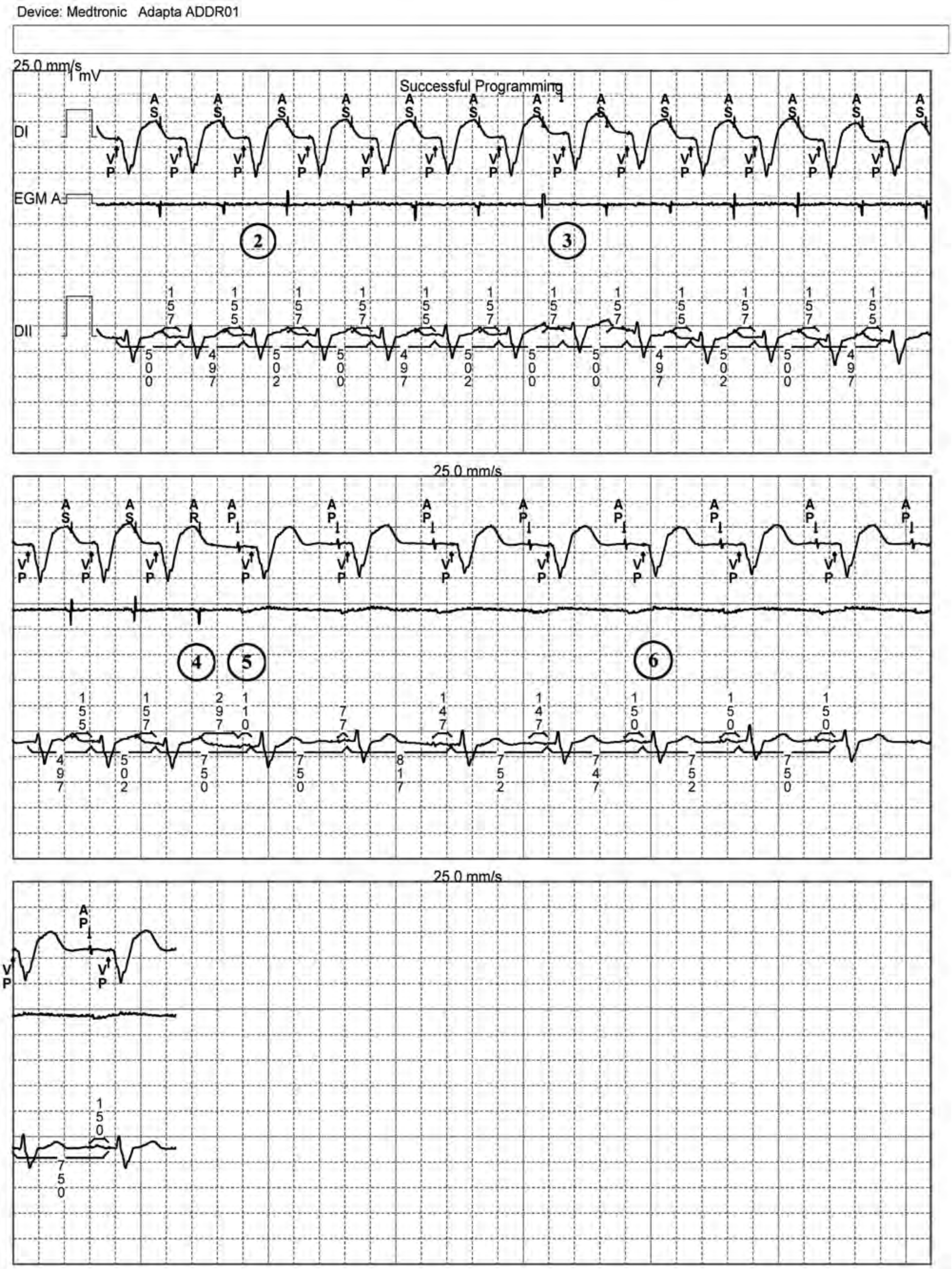
1) the algorithm for PMT interruption is not nominal programming; it must, therefore, be programmed on routinely, even in presence of AV block. It is indeed possible, as in this case, that anterograde conduction be interrupted and retrograde conduction preserved. It is also possible that it is absent at rest and present during exercise;

2) the interruption algorithm allows the distinction of sinus tachycardia from atrial tachycardia and PMT. Interruption of the tachycardia is highly in favor of PMT and, in this case, excludes sinus or atrial tachycardia. One needs to block retrograde conduction (VP-AS) only once or the AS-VP sequence to interrupt the tachycardia. The algorithm lengthens the refractory period, atrial retrograde activity no longer initiates an AV delay or a paced ventricular event and the tachycardia is interrupted;

3) in this sedentary 83-year-old patient, the PVARP can be programmed to 360 ms, i.e. longer than the retrograde conduction time. The programming of an AV delay that is relatively short and adaptive to exercise (paced AV delay of 140 ms during exercise) allows the setting of a 2:1 point at 120 bpm.

The programming of anti-PMT interventions is useful only when the retrograde conduction time is <400 ms and, therefore, does not intervene when it is > 400 ms. In such case, PMT remains incessant and the patient's management is particularly challenging. Strong efforts must be made to avoid all situations that might facilitate the onset of PMT. A possible remedy might be the prescription of a drug that blocks retrograde conduction, which is already slowed, though this measure is rarely effective. Ablation by radiofrequency is another option, though this need is very rare.


Device: Medtronic Adapta ADDR01
25.0 mm/s
1 mV
DI
EGM A
DII
AS
VP
25.0 mm/s
25.0 mm/s


Device: Medtronic Adapta ADDR01
25.0 mm/s
1 mV
Successful Programming
DI
EGM A
DII
2
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25.0 mm/s
25.0 mm/s

Case 6: PMT from loss of atrial capture

Patient

This 71-year-old patient underwent implantation of a Kappa dual chamber pacemaker for management of a prolonged, symptomatic PR interval; during a routine follow-up, the patient complained of dyspnea and frequent palpitation at rest.

EGM

The first channel is lead I of the surface ECG, upon which the markers are superimposed, the second channel are the atrial EGM and the last channel is lead III with the time intervals superimposed;

1: repetition of AP-VP-AR cycles; the atrial EGM shows absence of atrial capture (no atrial EGM visible after the pacing stimulus); ventricular capture is effective and followed by retrograde atrial conduction; the atrial signal which corresponds to the AR marker is a retrograde depolarization, instead of VA crosstalk from the late sensing of the QRS by the atrial channel; the conduction time is, indeed, relatively short and the atrial event, sensed inside the refractory period (AR), initiates neither an AV delay nor ventricular pacing;

2: incidence of possible premature atrial or of sinus event, with a foreshortened VP-AR delay; it is also possible that the atrial retrograde activity was detected earlier (sensing time varying with respiration, for example);

3: in this cycle the interval between VP and atrial sensing is prolonged, as the retrograde conduction time was lengthened; the atrial event no longer fell inside the refractory period, was labeled AS, and initiated an AV delay and a ventricular paced event;

4: onset of PMT; the rate of the tachycardia (120 bpm) slowed retrograde conduction compared with the beginning of the tracing; the atrial event no longer falls in the refractory period; the rate of the tachycardia is slower than the programmed upper rate, as it represents the sum of AV delay + retrograde conduction time;

5: trigger of the PMT interruption algorithm; prolongation of the refractory period for one cycle; the retrograde atrial event falls inside this refractory period;

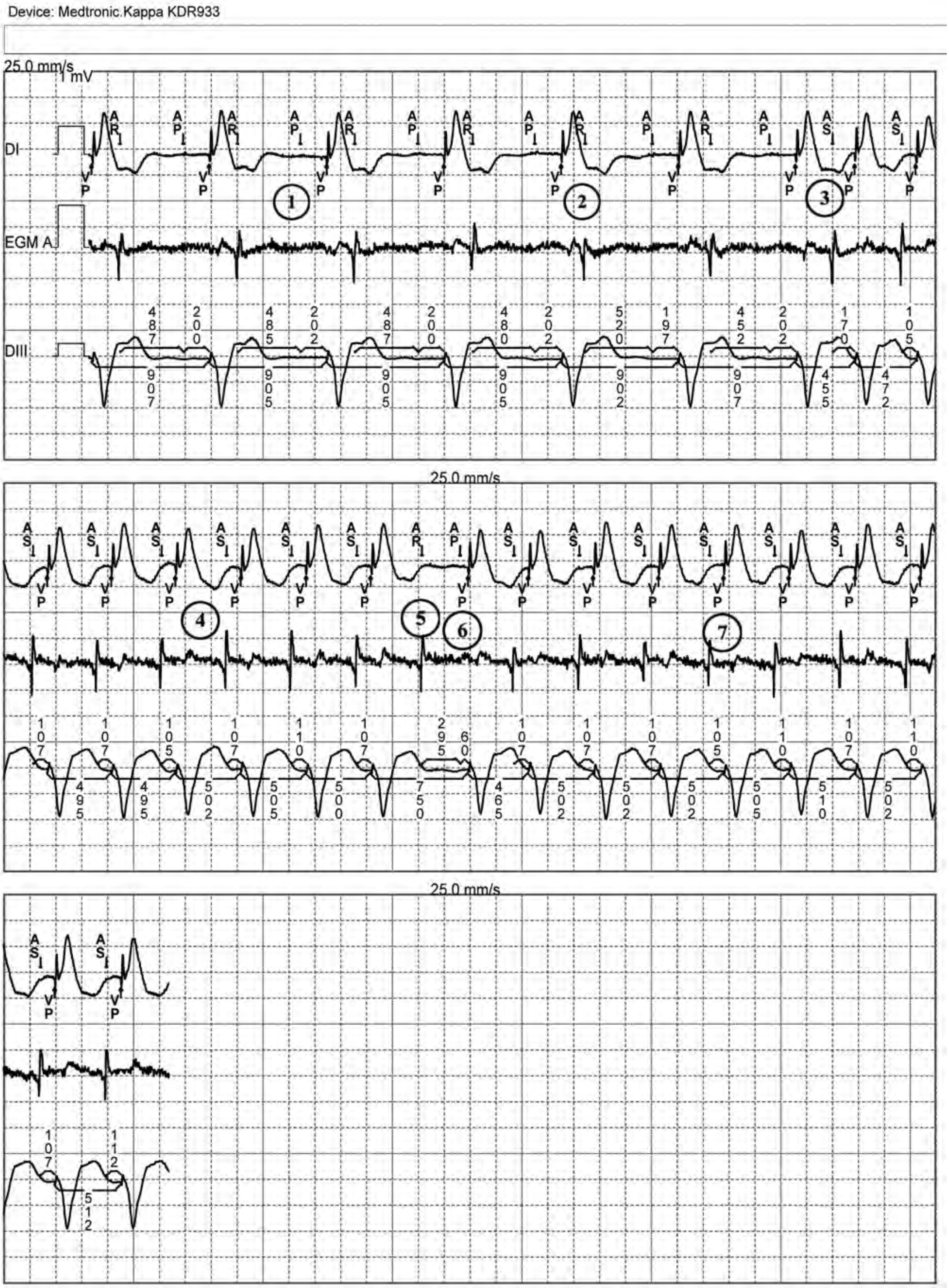
6: AV pacing with short AV delay (NCAP function); the EGM channel shows the absence of capture and retrograde conduction, excluding the diagnosis of sinus or atrial tachycardia, since this atrial activity is immediately linked to the occurrence of the preceding VP; atrial activity, instead of being independent, depends on ventricular events;

7: new PMT; it is noteworthy that after a first intervention, the interruption algorithm begins a second intervention after 90 sec, which explains the persistence of tachycardia;

Comments

This tracing highlights a key point of the management of PMT. While it is most important to program the PMT interruption algorithm 'on' , it is as critical to eliminate the source of their induction. The best treatment of PMT is their prevention. All events promoting a loss of AV synchrony has the potential of triggering a PMT in patients whose retrograde conduction is preserved. In this patient, the main dysfunction was loss of atrial capture. An increase in the amplitude of atrial pacing with a sufficient pacing margin of safety solved this dysfunction.

Another programming option can be considered for this patient who presented with complete AV block and sinus node dysfunction: if, despite the programming changes, the onset of PMT persists, the DDIR mode would allow atrial and ventricular pacing and rate responsiveness, as well as the definitive elimination of PMT (sensing of an atrial event in DDI mode initiates neither an AV delay nor ventricular pacing).


Device: Medtronic.Kappa KDR933
25.0 mm/s
1 mV
DI
EGM A
DIII
25.0 mm/s
25.0 mm/s

Case 7: PMT

Patient

This 68-year-old man, who presented with ischemic cardiomyopathy and a 45% left ventricular ejection fraction during treatment with a beta-adrenergic blocker, underwent implantation of an Adapta pacemaker programmed in DDD mode for the management of symptomatic, paroxysmal sinus node dysfunction; AV conduction is preserved and the PR interval is normal; he was seen in consultation for evaluation of palpitations and heart failure.

EGM

The first channel is lead I of the surface ECG, upon which the markers are superimposed, the second channel is the atrial EGM and the last channel is lead II with the superimposed time intervals;

1: atrial sensing-ventricular pacing (AS-VP); a first question that must be addressed is whether the mode that initiates ventricular pacing is the optimal choice in this patient presenting with sinus node dysfunction;

2: slowing of the sinus rate and AP pacing are clearly ineffective; the atrial EGM shows activity occurring after VP that is not sensed by the device, as it falls in the post-ventricular atrial blanking period; it is likely sinus activity instead of retrograde conduction, since the interval between VP and atrial events is too short; the atrial signals on the EGM channel are similar to the preceding AS sinus signals;

3: same sequence, though the sinus cycle falls further behind VP, and is, therefore, labeled AS and initiates an AV delay and ventricular pacing;

4: onset of PMT with retrograde conduction; the atrial EGM is now different from those observed in a sinus cycle;

5: retrograde conduction remains fixed for 5 cycles before ending spontaneously, causing an interruption of PMT; retrograde conduction is an indispensable ingredient in the perpetuation of PMT;

6: return of sinus rhythm (AS-VP);

7: same sequence as the previous: sinus slowing, ineffective atrial pacing, PMT, spontaneous interruption;

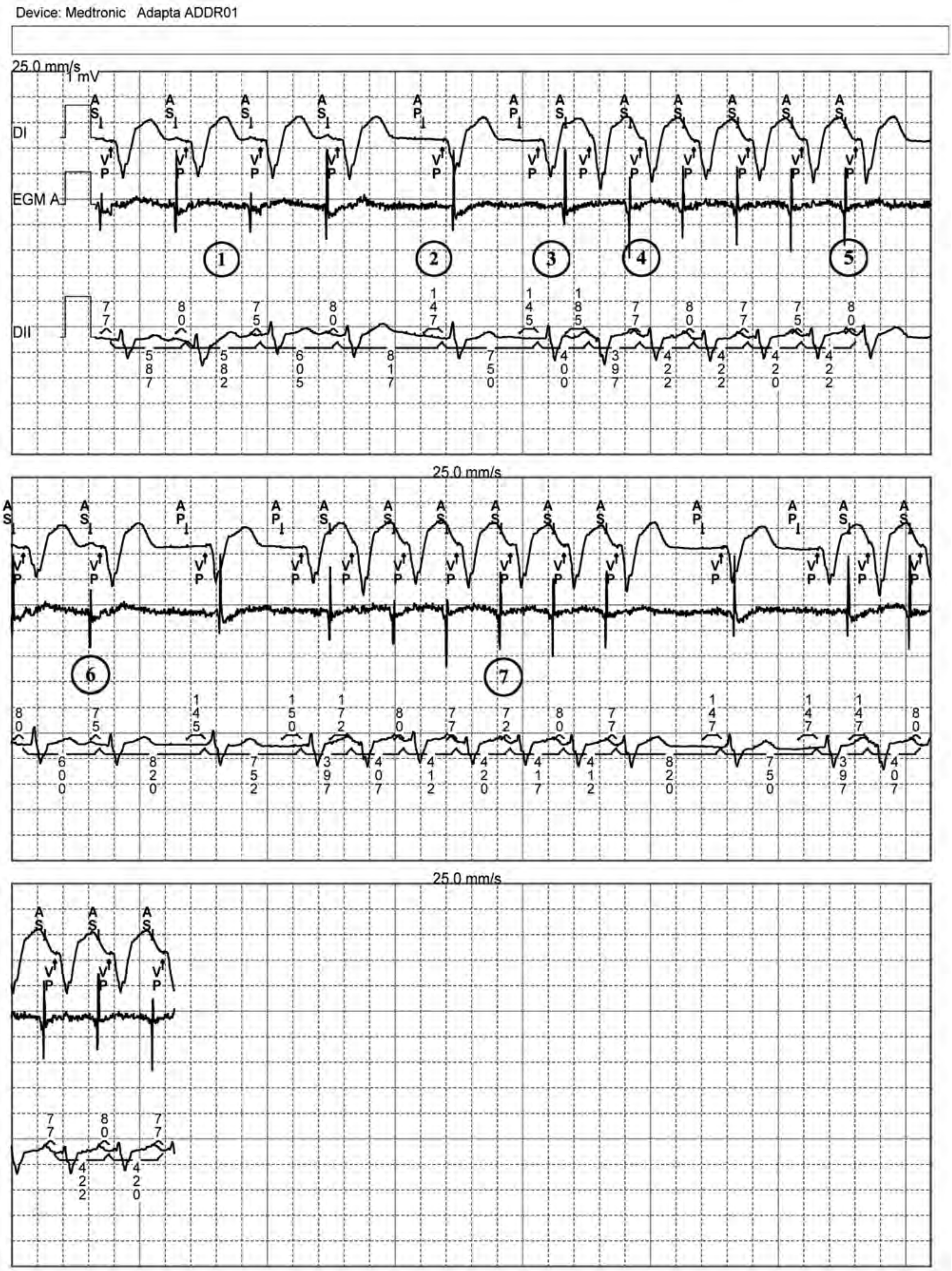
Comments

This interesting tracing shows multiple episodes of PMT, which end spontaneously. These episodes were not stored in the device memory. While the PMT interruption algorithm was, indeed, programmed 'on', the episodes were so short that the algorithm did not intervene (≥8 consecutive cycles are needed for a diagnosis to be made by the algorithm with interruption of PMT). These incessant episodes of tachycardia were probably responsible for heart failure. In this patient it was best to:

1) set the amplitude of atrial pacing such that there was consistent capture;

2) program to the MVP mode, as anterograde conduction was preserved with a satisfactory PR interval. A decrease in the percentage of ventricular pacing might also have a short- and long-term beneficial effect on the short and long term;

3) after programming of the MVP mode, the risk of PMT is lower, though persists if the pacemaker switches to DDD mode. Therefore, the PVARP should be lengthened beyond the retrograde conduction time, which, during these episodes, varied between 320 and 340 ms. Programming should also include a relatively short AV delay with rate-adaptive AV delay 'on' so that a reasonable maximum tracking rate can be maintained if the mode switches to DDD.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25.0 mm/s
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Case 8: PMT

Patient

Same patient as in tracing no 5; this episode was recorded during interrogation of the device.

EGM

The first channel is lead I of the surface ECG, upon which the markers are superimposed, the second channel is the atrial EGM and the last channel is lead II with the superimposed time intervals;

1: atrial sensing, ventricular pacing (AS-VP);

2: ventricular extrasystole (VS); crosstalk between this ventricular extrasystole and the atrial channel; AS even precedes VS; depending on the leads placement and the origin of the premature events, some ventricular extrasystoles might be sensed earlier in the atrium than in the ventricle; the clearly visible spontaneous atrial event, which occurs immediately after the extrasystole on the atrial EGM channel, was not sensed since it fell in the post-ventricular atrial blanking period of the extrasystole;

3: another ventricular extrasystole with crosstalk;

4: atrial event (AS), further away, is sensed and initiates an AV delay and ventricular pacing; the AV delay was lengthened to observe the shortest programmed VV delay, corresponding to the programmed upper rate;

5: triggering of PMT;

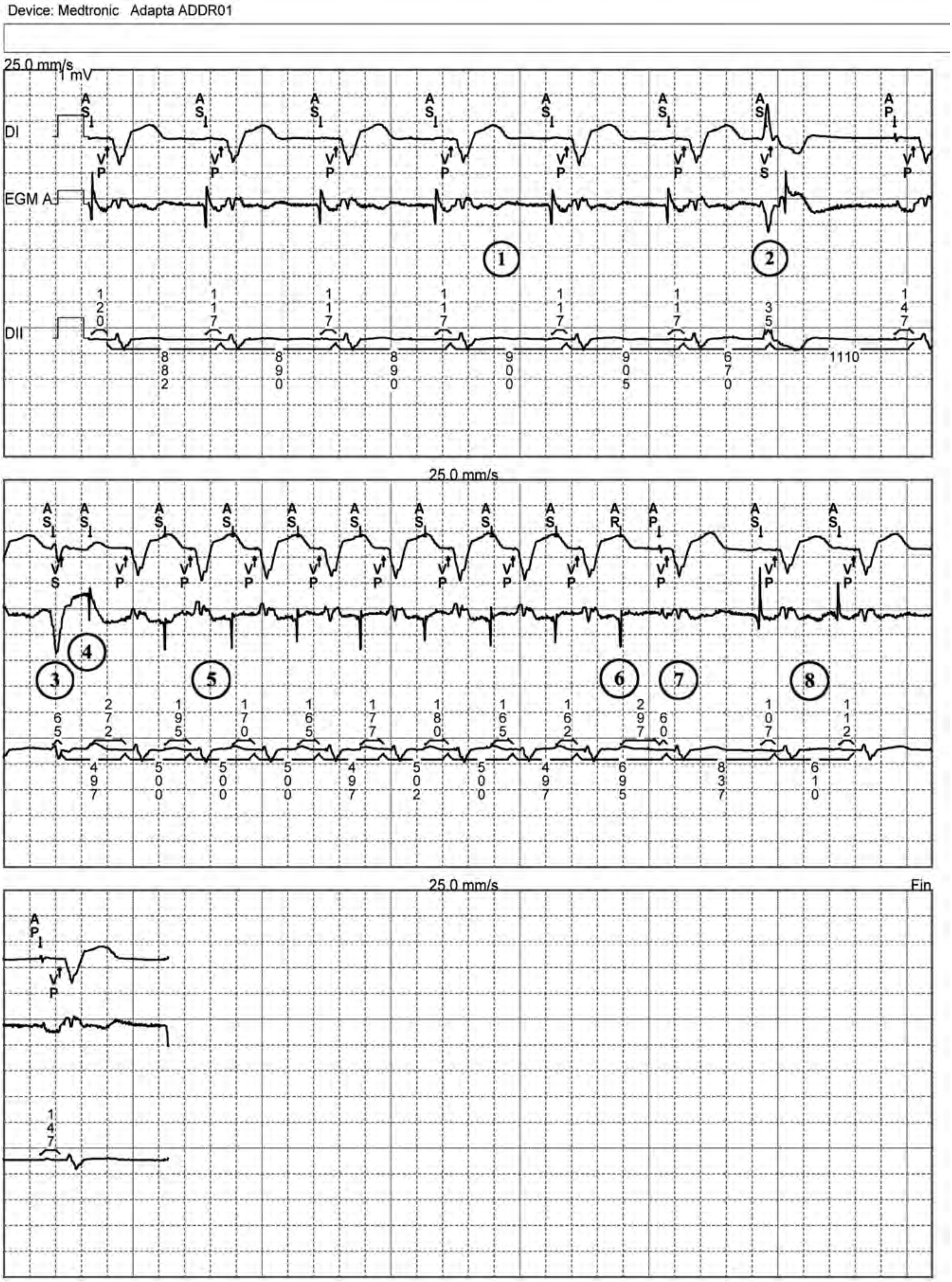
6: interruption of PMT by the algorithm;

7. AV pacing with short AV delay (NCAP);

8: return of sinus rhythm (AS-VP);

Comments

The management of premature ventricular contraction by a dual chamber pacemaker is a particular challenge. A ventricular extrasystole may, indeed, cause a loss of AV synchrony, which, as on this tracing, might trigger a PMT. The algorithm of response to ventricular extrasystoles is designed to prevent the sensing of retrograde P waves originating from these extrasystoles. The pacemaker defines as a ventricular extrasystole, a sensed ventricular event following another ventricular event without atrial event contained in the VV interval. The challenge, with this patient, was the early crosstalk of a ventricular extrasystole on the atrial channel. This cycle, analysed as an AS-VS by the pacemaker, is not counted as a ventricular extrasystole. It might be possible to lower the atrial sensitivity to eliminate the crosstalk. Indeed, even if the amplitude of the atrial signal caused by the ventricular extrasystole is sensed on the atrial channel, it is also of lower frequency than an atrial signal of sinus origin. A change in the sensing of atrial events might eliminate this oversensing.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1110

Pacing & Exercice

Cardiac pacemaker and programming for exercise

Various parameters must be programmed and optimized to allow the adaptation of pacing to exercise. The main objectives of a specific programming dedicated to exercise are to ensure a proper contribution of atrial systole to the cardiac output at high rates while preserving AV synchrony, and allow an adapted increase in heart rate, which represents the main adaptive factor of the cardiac output to exercise.
The performance of an exercise test is an important evaluation in a pacemaker recipient, which allows:

- the verification of proper pacemaker function, including a) adapted changes in rate, b) reliable sensing and pacing, which might change with breathing, changes in posture and with motion, and c) preservation of AV synchrony
- the evaluation of residual symptoms or development of new, exercise-induced symptomatology
- the programming and optimization of specific parameters that vary as a function of the heart rate (AV delays and adaptable PVARP)
- to find electrophysiologic changes due to exercise (retrograde conduction present during exercise and absent at rest)
- to evaluate the need for rate responsiveness

Various exercise tests can be used in pacemaker recipients, with ideally the ability to record simultaneously a surface electrocardiogram and intracardiac electrograms, using the programmer to identify dysfunction and fix it in real time.
Standard exercise tests help to evaluate the general functions of the pacemaker and rate-adaptive sensor(s). The heart rate adaptation to treadmill exercise seems more gradual and closer to that observed in real life than that achieved on a bicycle. The bicycle recruits muscle masses in the inferior extremities that are distant from the pulse generator, such that the sensor is activated later. At an equal load, the increase in rate is greater on a treadmill than on a bicycle.
Standardized real-life tests may be appropriate given that a large proportion of pacemaker recipients are elderly and limited in their daily activities, such as walking, self-grooming, fixing meals, and housekeeping. The type of exercise test must, therefore, be tailored to these specific activities. Various kinds of exercise can be performed during electrocardiographic surveillance, such as walking on level ground, flexion of the lower extremities, etc.

Atrioventricular synchronization during exercise

When the device operates in DDDR, DDD or VDD mode, it can synchronize atrial rhythms up to a rate limit. The limits of atrial synchronization are, in particular, the 2:1 block rate and the programmed synchronous upper rate.

The 2:1 block point

The sum of the AV delay and the PVARP represent the total atrial refractory period (TARP). All atrial events sensed outside the TARP is able to initiate an AV delay followed by ventricular pacing. Conversely, when the cycle of the intrinsic atrial rate is shorter than the TARP, every other atrial event falls in the PVARP and is followed neither by an AV delay nor by ventricular pacing. Ventricular tracking occurs on an alternate basis and 2:1 AV block is installed, with every other P wave followed by an AV delay and a ventricular pacing event. When the pacemaker is in DDD or VDD modes, the ventricular pacing rate falls precipitously, and the ventricular pacing rate is 50% of the ongoing sinus rate.

As an example, a patient with complete AV block and an AV delay set at 150 ms has a PVARP at 300 ms and an upper rate at 150 bpm. The 450 ms TARP duration corresponds to a rate of 133 bpm.

- as long as the sinus rate remains between the back-up rate and 133 bpm, the AV relationship is 1 :1, with each P wave followed by a paced QRS;
- if the sinus rate exceeds 133 bpm, every other P wave is followed by a paced QRS, whereas every other P wave falling in the PVARP is blocked and the ventricular rate decreases suddenly to 66.5 bpm.

The sudden decrease in cardiac output associated with this sudden heart rate slowing may be associated with disabling symptoms. However, the decrease in heart rate might be mitigated by various rhythms stabilizing functions or smoothing.

Consequently, the 2:1 point must be set as high as possible to enable the 1:1 tracking of the sinus P waves over the entire range of rates that might be observed in any given patient. The TARP duration (AV delay + PVARP) must, therefore, be shortened during exercise, which can be achieved by programming an automatic shortening of AV delay and PVARP during exercise.

Synchronous upper rate and pseudo-Wenckebach operation of the pacemaker

In the presence of complete AV block and during exercise, when the sinus rate remains below the programmed upper rate, each P wave is followed by ventricular pacing at the end of the AV delay. When the sinus rate accelerates and surpasses the programmed synchronous upper rate, a ventricular pacing event occurring at the end of the programmed AV delay would surpass the programmed upper rate, which is not possible. The ventricular rate can no longer follow the atrial rate on a 1:1 basis and hovers near this value. In order not to violate this limit, the pacemaker lengthens the AV delay and begins to operate in a pseudo-Wenckebach mode. As the sinus rate accelerates beyond the maximum synchronous rate, the ventricular pacing rate remains at the upper synchronous rate and the observed sensed AV delay lengthens with each paced cycle. After several cycles, an atrial event occurs during the PVARP and is not tracked, resulting in a longer V-V cycle. The following P wave is outside all refractory periods and initiates a new programmed AV delay. This sequence repeats itself as long as the sinus rate remains above the programmed maximum synchronous rate.

The longer V-V cycle occurs less often if the sinus rate is only very slightly faster than the maximum synchronous rate, though more if it surpasses it greatly. As soon as the sinus rate falls below the upper rate, the 1:1 association returns.

The pseudo-Wenckebach behavior can be defined by the frequency with which the longer V-V cycle occurs and by the sensed atrial: paced ventricular events ratio (for example, 8:7, 7:6, 6:5 or 3:2). When the increase in sinus rate reaches the 2/1 point, a major decrease in ventricular rate occurs along with a 2:1 atrial/ventricular ratio.

The upper synchronous rate is usually programmed at a rate below the 2:1 rate during exercise. If not, the 2:1 block rate becomes the absolute limit and the maximum synchronous rate cannot be reached.

Specific programming to preserve atrioventricular synchronization during exercise

Adaptable atrioventricular delay

In the healthy heart, the PR interval shortens physiologically during exercise, on average 4 ms per 10 cycles of rate acceleration. Furthermore, the duration of the A wave shortens considerably during exercise, with acceleration of the speed of the transvalvular flow as a consequence of the increase in atrial contractility caused by catecholamines and cavity filling.

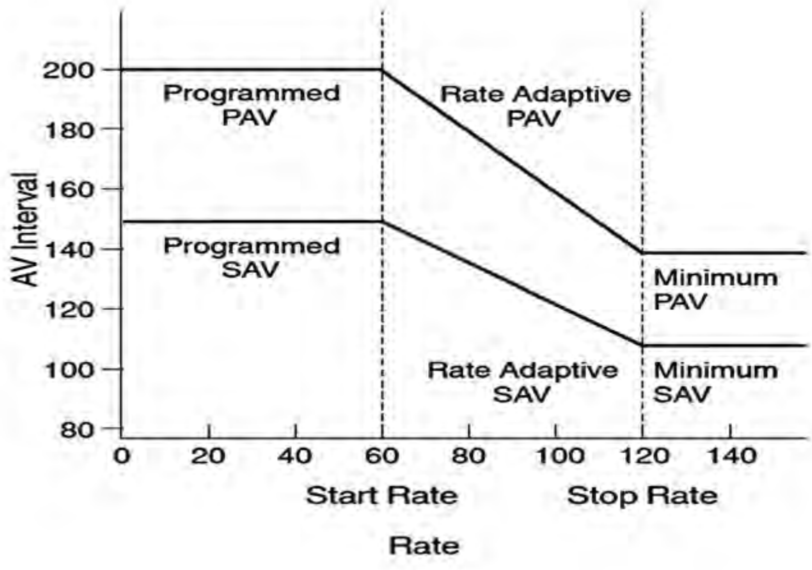
The adaptation of the AV delay that can occur when the pacemaker operates in DDDR, DDD, DDIR, DVIR, DOOR or VDD modes, simulates this physiological response. The same variation is applied to the sensed and paced AV delay. In MVP mode (AAIR<=>DDDR or AAI<=>DDD), the adaptable AV delay functions only when MVP is in DDDR or DDD mode.

This function improves the sensing and synchronization to atrial activity. The sensed AV delays that are shortened during exercise widen the sensing window of rapid atrial events by shortening the TARP and increasing the rate of 2:1 block onset. The adaptable AV delay adapts the latter linearly as the heart rate varies.

With regard to the adaptable AV delay function, the sensed and paced AV delays are set to the values desirable for slow rates. Three additional programmable settings govern the adaptation of the AV delay at faster rates:

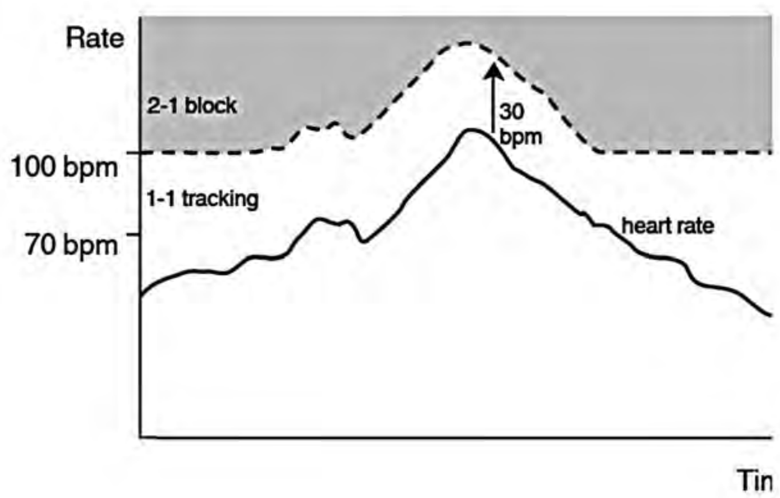
- the start rate: the shortening of the sensed and paced AV delay begins at that rate.
- the stop rate: the shortest sensed and paced AV delay does not shorten further from there and up to the programmed upper rate.
- the maximum variation: the greatest shortening (in ms) of the sensed and paced AV delays.

The paced AV delay minus the maximum variation equals the shortest paced AV delay at the stop rate (for example 200 ms - 100 ms = 100 ms). By subtracting the maximum variation from the sensed AV delay, one derives the shortest sensed AV delay (for example 170 ms - 100 ms = 70 ms).



PVARP auto

Besides the shortening of the AV delay, the TARP can be decreased by progressively shortening the PVARP as the rate accelerates. When the automatic PVARP is programmed, the pacemaker determines its value as a function of the average atrial rate. The automatic PVARP increases the 2:1 block rate by shortening the PVARP and the sensed AV delay (if pertinent) at higher tracking rates, and protects against PMT at low rates with a longer PVARP.
The automatic PVARP is available when the device is programmed in DDDR, DDD, DDIR, DDI, AAIR<=>DDDR or AAI<=>DDD modes, and adapts the PVARP in response to changes in heart rate. In MVP mode (AAIR<=>DDDR or AAI<=>DDD), the automatic PVARP functions only when the MVP is in DDDR or DDD mode.



Maximum synchronous rate

The choice of upper rate depends on the patient's age, underlying heart disease, exercise capacity, retrograde conduction time and on the performance of the arrhythmia- (fallback) and PMT-control algorithms. It seems appropriate to ensure the 1:1 tracking of the entire range of sinus rate of individual patients, and avoid the programming of an excessively slow synchronous upper rate. The development of AV dissociation due to pseudo-Wenckebach periodicity indeed causes an increase in myocardial oxygen consumption and a fall in cardiac output and arterial pressure that are often poorly tolerated.

Atrial sensitivity

The 1:1 AV tracking during exercise requires a flawless quality of atrial sensing. Exercise and the increase in the amplitude of the respiratory movements are often associated with a degradation of atrial sensing, which, in pacemaker-dependent patients, can cause a fall in the ventricular pacing rate, in which case it is necessary to increase the safety margin by increasing the programmed sensitivity.

Rate responsive pacing

Some patients suffer from chronotropic insufficiency and inadequate increase in heart rate during physical activity. This inability to increase the heart rate with exercise can be associated with symptoms such as dyspnea, fatigue or limited exercise capacity.

State of the art cardiac pacemakers include sensors capable of monitoring the activity level and accelerate the pacing rate accordingly. A rate responsive pacemaker is a device with a base rate that varies according to the information provided by a specific activity sensor. Its aim, in the presence of chronotropic insufficiency, is to ensure an increase in cardiac output that is as physiologic as possible and corresponding to the instantaneous metabolic needs imposed by exercise.
A rate responsive pacemaker is identified by the 4th letter (R) of the international code: SSIR, DDDR, DDIR, and others.

Each device manufacturer offers its particular sensor and programming of the rate responsiveness. While several types of systems have been developed since the 1970s, three only remain in use in the current devices depending on the models, including the monitoring of physical activity by a piezoelectric quartz or by an accelerometer, and minute-ventilation, using the bio-impedance technique.

The criteria for a physiologically appropriate rate response sensor are:

- the information provided must be directly related to the activity of the sympathetic nervous system or with the patient's physical activity;
- the relationship between the amplitude of the sensor-generated signal and the level of exercise must be linear;
- the sensitivity of the sensor must be optimal to ensure a rapid reactivity of the system;
- the range of variation of the parameter that is monitored must be wide enough to meet the patient's physiologic needs;
- the information provided must be reproducible;
- the sensor must be as small as possible to be incorporated in the pacemaker without increasing its size, and consume a minimum amount of energy.

The rate response of Medtronic pacemakers includes a) an activity sensor that measures the patient's motion, b) a rate calculation tool that converts the level of physical activity to a pacing rate, and c) an optimization function of the rates histogram to automatically adjust the rate response parameters over time and the acceleration and deceleration functions in order to smooth the pacing rate. The algorithm offers a dual slope rate response, which can be automatic or manual.

Activity sensor

The activity sensor is an accelerometer embedded in the device, which detects the patient's body motion. Since the activity sensed varies among patients, the motion sensitivity can be adjusted by reprogramming the activity threshold parameter. By lowering the threshold, the pacing rate is modulated by less prominent motion, whereas an increase in threshold requires more marked body motion to modulate the pacing rate. If the threshold is increased, the body movements must be greater to have an effect on the pacing rate. The activity counter used to calculate the sensor rate is regulated by the rate and amplitude of the accelerometer signal.

The pacing rate is determined by the patient's level of physical activity and by the rate response parameters. At rest, for example when the patient is sitting, the pacing rate is near the backup rate. During increasing activity, for example when the patient is walking, the pacing rate increases.

The main advantages of accelerometers are their simplicity, reliability, low energy consumption, use of standard leads, high sensitivity at the onset of exercise, and high correlation between physical performance and rate acceleration, observed under various conditions, including walk and daily life activity. Furthermore, the response is more physiologic than with a piezoelectric sensor, because it is less sensitive to vibrations and is more closely correlated with the level of exercise.

Programmable rates

The lower rate corresponds to the slowest rate at which pacing occurs in absence of a sinus rate or physical activity.

The activities of daily living rate (ADL rate) is the approximate rate that the patient must reach during moderate exercise, defining a level that helps maintaining a stable pacing rate during changes in moderate activities, such as walking or household chores.

The upper sensor rate is the upper sensor-driven rate limit reached during vigorous exercise.
An independent control of the rate response is ensured in the range of ADL rates and in the range of maximum exertion rates. The pacemaker maintains a linear relationship between the signal of the activity sensor and the response rate 1) between lower and ADL rates, and 2) between back-up and the maximum exertion rates. The rate optimization system has an effect on the slope of the linear relationship in both rate ranges.

Rate response set points

The setpoints define the 2 characteristic slopes of a dual slope rate response.

A low setpoint indicates that relatively low intensity activities are needed to reach the maximum rate.

The ADL setpoint determines the pacing rate toward the ADL rate.

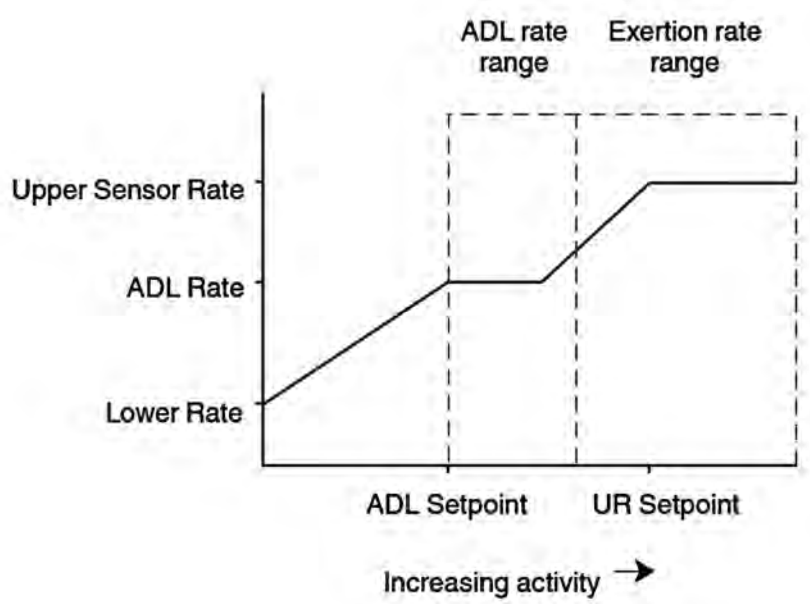
The upper rate (UR) setpoint determines the pacing rate toward the maximum rate response.

Automatic rate response

With the automatic rate response, the optimization of the rates histogram continues to adjust the rate curve by automatically varying the setpoints. The rate response is adjusted on the basis of the programming of the ADL response and exertion response parameters.

The ADL response controls the first slope, which determines the steepness of the increase in pacing rate between the lower rate and the ADL rate. The exertion response controls the second slope, which determines the steepness of the increase in pacing rate as it approaches the maximum response.

The rate response function is active for only 30 minutes after implantation.



Manual rate responsiveness

With the use of the manual rate response, a rate profile is obtained during a patient session, at which time the rates and set points are programmed.

This rate profile remains constant until the parameters are reprogrammed.

Optimization of the rate histogram

The optimization of rates histogram adjusts automatically the patient's rate response between office visits.

The aim of the rates histogram optimization is to ensure that the rate response remains appropriate for the entire range of individual patient's activities. The device collects and records daily averages and, on the long term, the percentage of time during which the sensor-indicated rate is at various pacing rates. It then uses the ADL and the exertion response parameters to analyze the percentage of time during which the pacing rate remains in the ADL versus the exertion ranges.

Based on daily comparisons, the device adjusts the ADL, the UR, or both setpoints.

Adjustment of the activity threshold

The activity threshold parameter does not need to be reprogrammed in a high proportion of patients.

However, when a patient presents with an insufficient rate response during exercise, the activity threshold can be reprogrammed to a lower (more sensitive) level. The most sensitive level is "Low". Conversely, if the pacing rate is high at rest, the activity threshold might need to be reprogrammed to a higher (less sensitive) level. The least sensitive level is "High".

Rate profile optimization

Before programming the other rate response parameters, one must first verify that the lower rate, ADL and upper sensor rates settings are appropriate for each patient.

If the reprogramming of the rates has not optimized the rate profile, it might be necessary to reprogram the ADL and Exertion Response settings. The reprogramming of these parameters can design a rate profile that corresponds to the individual life style or activity levels within each range of rates.

The ADL response is adjusted in order to set the speed at which the patient reaches the ADL rate and the Exertion Response for the speed at which the patient reaches the exertion rate. In both cases, a lower value decreases, while a higher value increases the rate response.

Manual adjustment of the set points

The rate profile optimization can be programmed OFF, allowing the manual programming of the setpoints, in which case a) the ADL and UR points determine the pacing rate profile, and b) the rate response calculations continue as programmed.

Case 1: Shortening of the AV delay during exercise

Patient

This 72-year-old male recipient of a pacemaker for complete AV block due to degenerative conduction system disease suffered from coronary artery disease treated with a beta-adrenergic blocker. The device was programmed to the DDDR mode, with a backup rate at 60 bpm, upper rate response at 120 bpm, and an adaptive paced AV delay between 200 and 120 ms; the tracings were recorded at various stages of effort, consisting of repetitive flexing of the legs performed with a telemetry head held over the pacemaker.

EGM

Tracing 1a: the first channel is lead I of the surface ECG with the event markers superimposed, the second channel shows the time intervals, the third is lead III and the fourth channel is lead II;

1: after 30 sec of repetitive flexing of the legs, the heart rate is 80 bpm and the paced AV delay is 200 ms;

Tracing 1b: slightly greater effort;

2: the heart rate is 90 bpm and the paced AV delay is 187 ms.

Tracing 1c: moderate exercise;

3: the heart rate is 100 bpm and the paced AV delay is 162 ms.

Tracing 1d: vigorous effort;

4: the heart rate is 110 bpm and the paced AV delay is 147 ms.

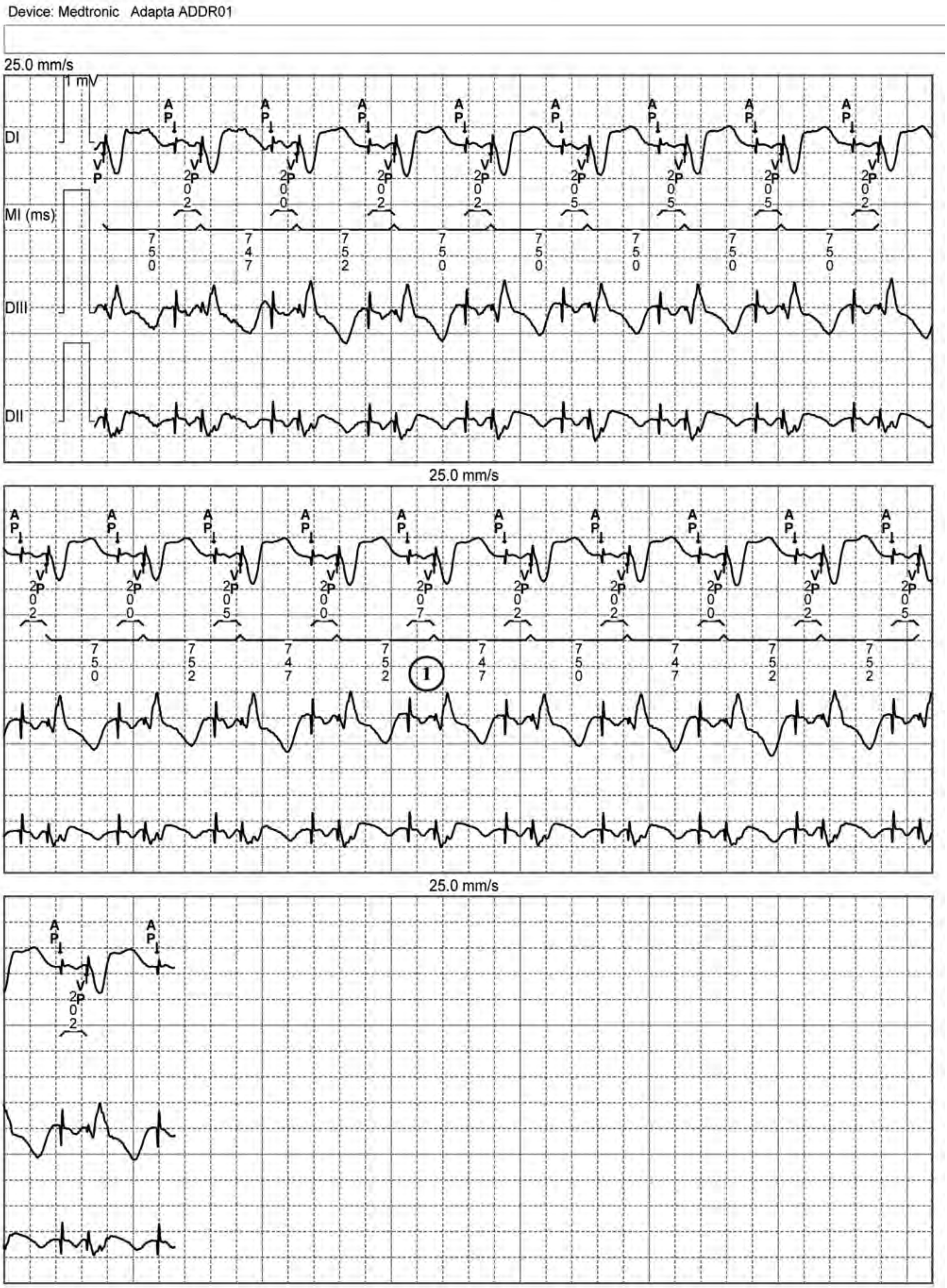
Tracing 1e: maximum effort;

5: the heart rate is 120 bpm and the paced AV delay is 120 ms.

Comments

This tracing illustrates the functions of the adaptive AV delay and the 3 programmable parameters which govern the means by which the AV delay is adapted to increasing heart rates: in this patient, the backup rate was programmed at 60 bpm with a paced AV delay programmed at 200 ms. The first parameter is the heart rate at onset of shortening of the AV delay, which, in this case, is programmed at 80 bpm. Shortening of the AV delay, whether sensed or paced, begins at that rate (start rate) and the adaptive function adapts the AV delay linearly as the heart rate increases up to the stop rate, programmed in this case at 120 bpm. The shortest sensed and paced AV delays develop from this rate up to the maximum programmed rate response (which can be identical or different). The third parameter is the maximum variation, which corresponds to the range of variations of AV delays, between start and stop rate. In this case, the widest variation was programmed at 80 ms, explaining the difference between an AV delay at 200 ms at the start rate and an AV delay at 120 ms at the stop rate.

The programming of the adaptive AV delay has 2 main objectives: 1) emulation of the physiologic response, by which the PR interval shortens during exercise from the effects conferred by catecholamines, and 2) the spontaneous shortening of the AV delay during an increase in heart rate optimizes the sensing window of rapid atrial events by shortening the total atrial refractory period and by increasing the rate of onset of 2:1 block.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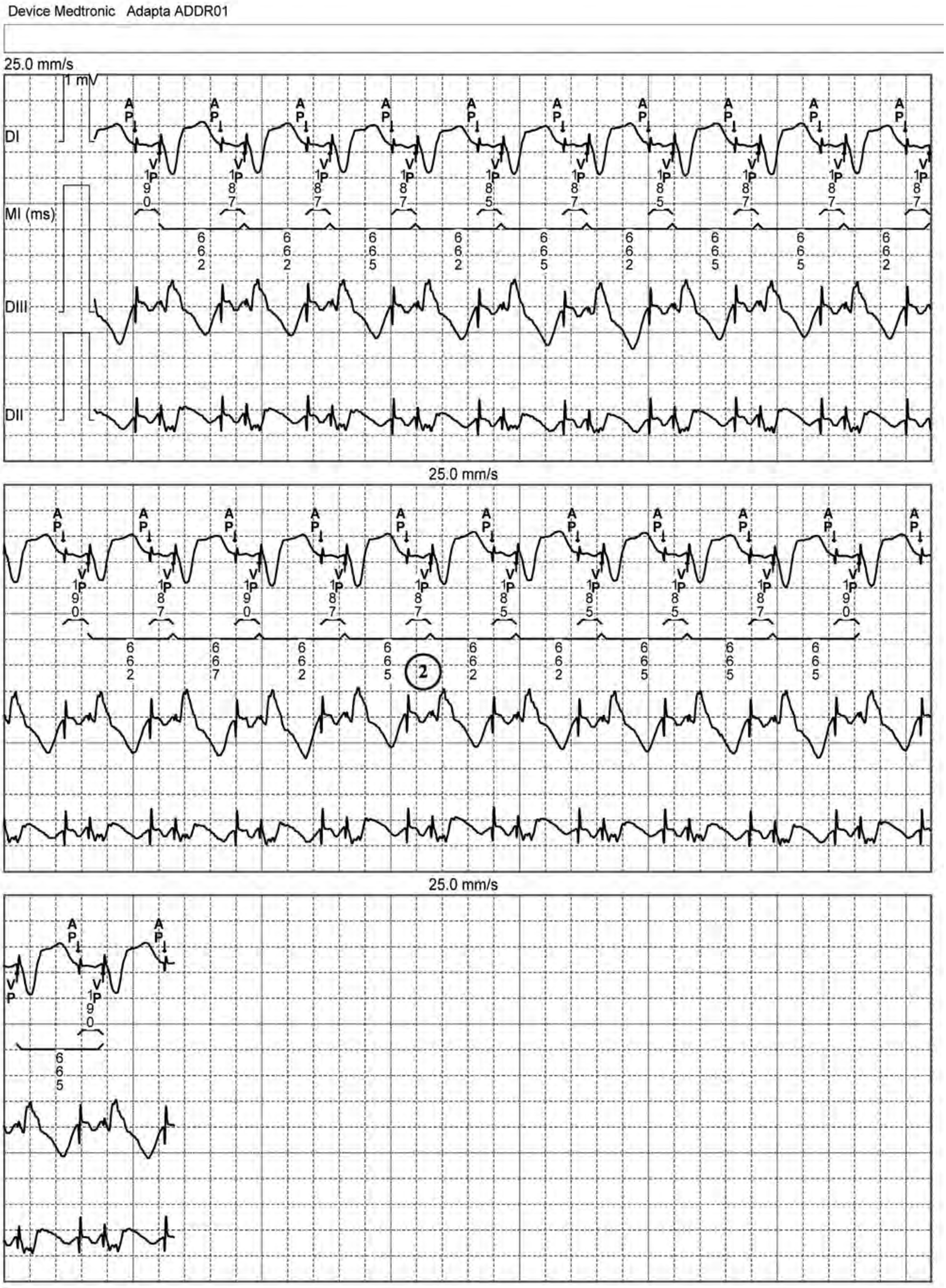
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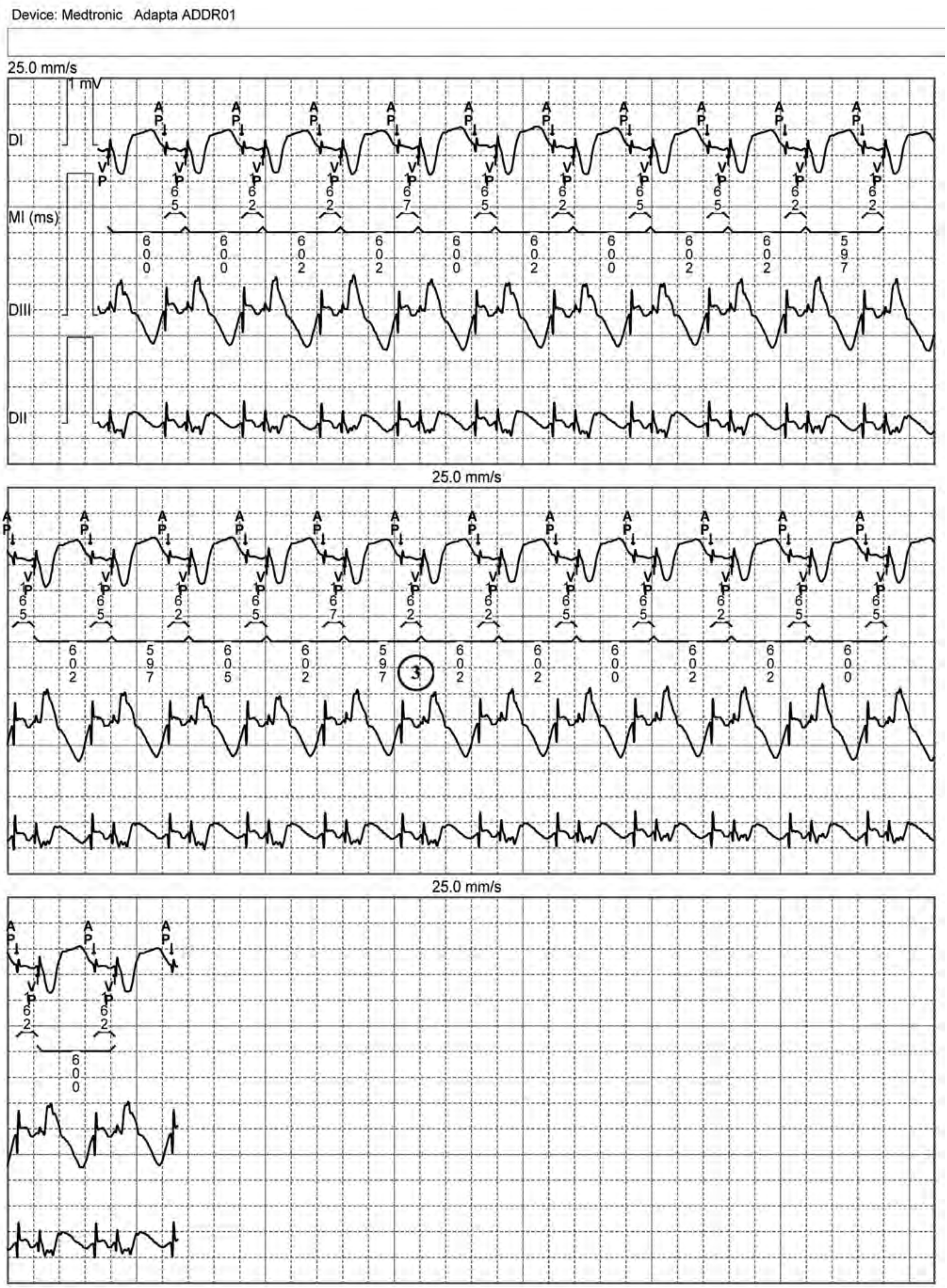
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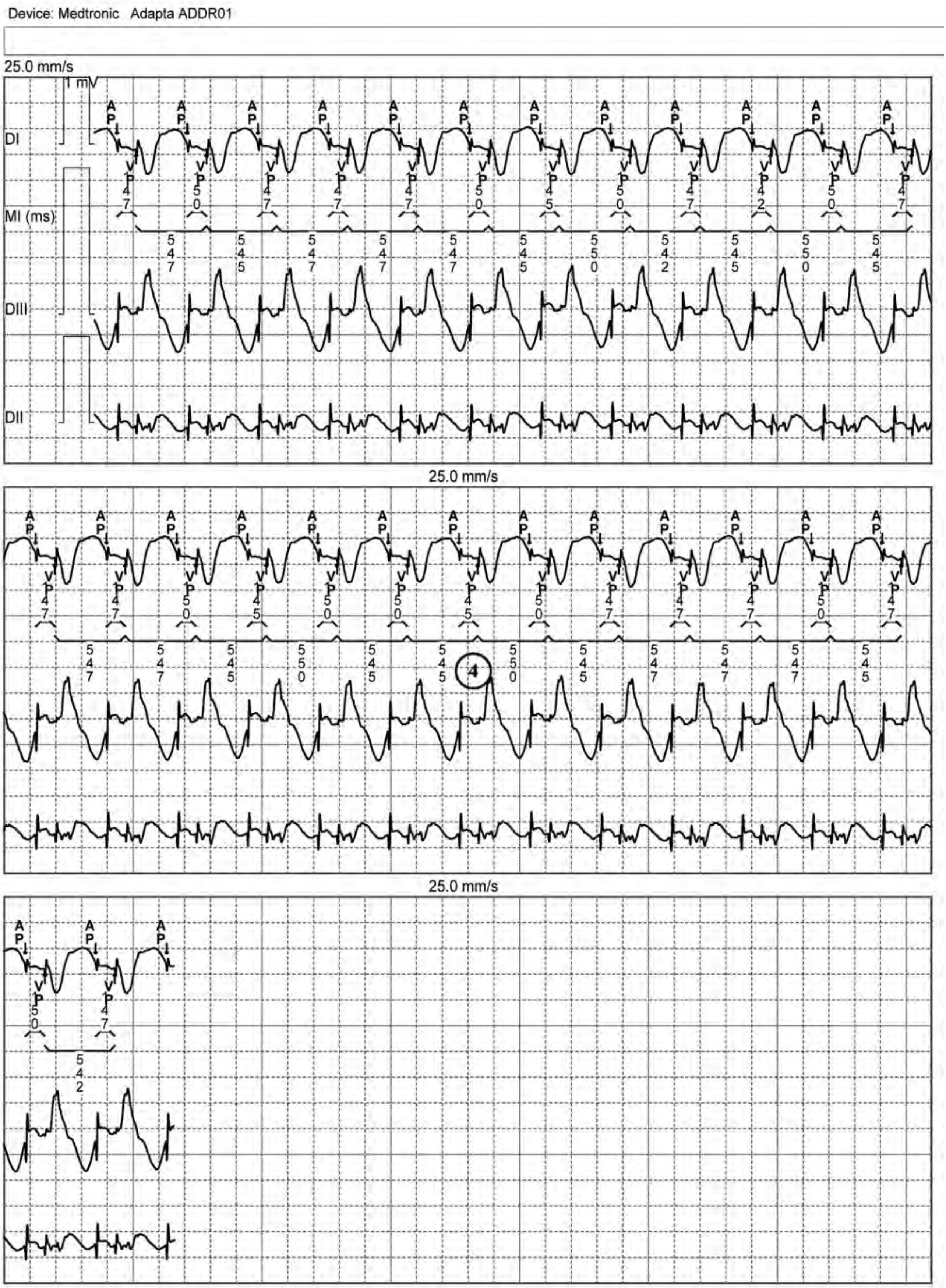
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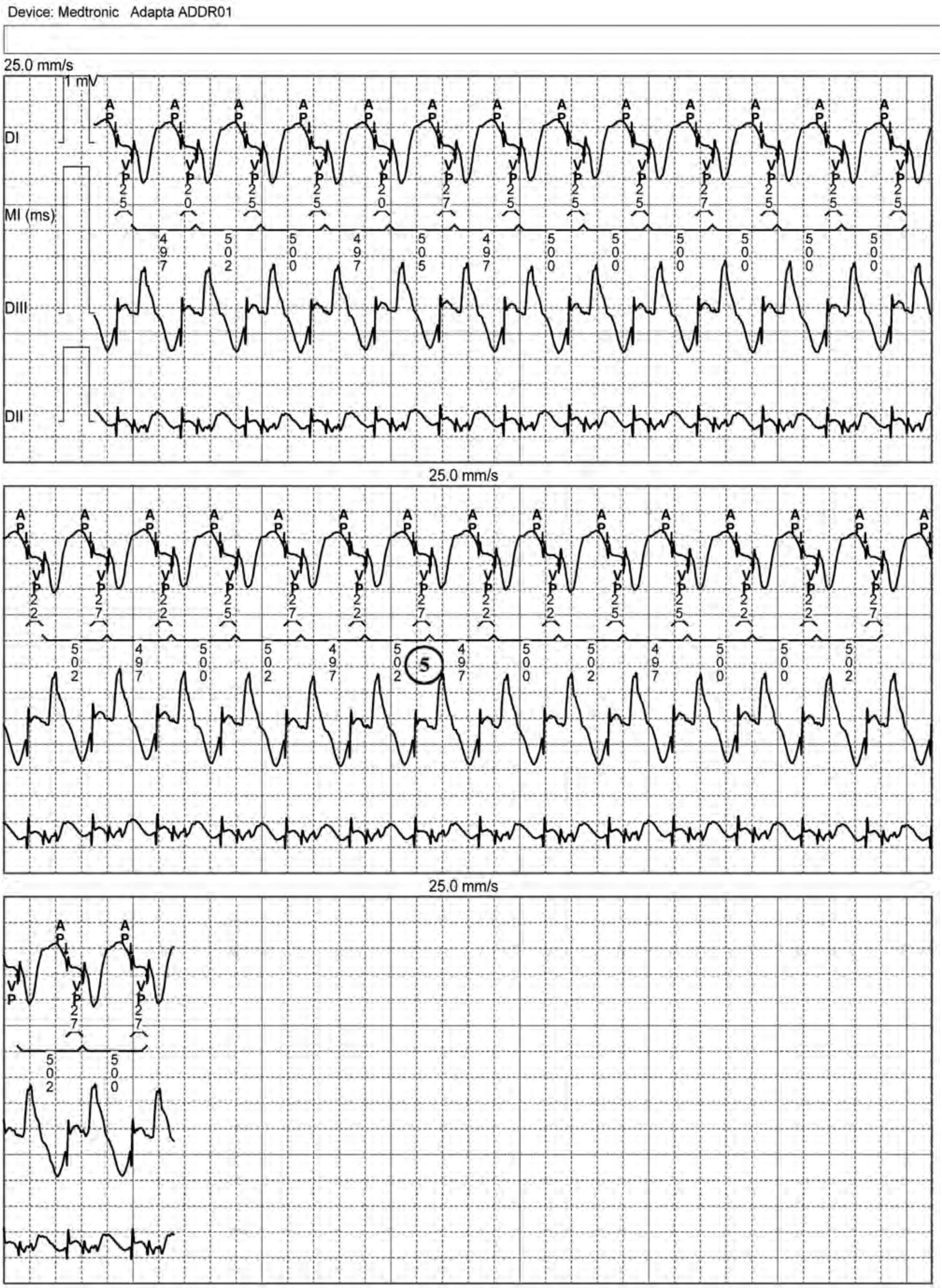
DII
AP
VP
4


Device: Medtronic Adapta ADDR01
25.0 mm/s
1 mV
DI
MI (ms)
DIII
DII
25.0 mm/s
5
25.0 mm/s

Case 2: Failure of rate response

Patient

This 63-year-old man received an Ensura DR MRI dual chamber pacemaker for management of syncopal events due to complete AV block and degenerative disease of the conduction system; EGM were recorded at the beginning of his first post-implantation follow-up, with the device programmed in DDD mode.

EGM

1: programmed in AAI⇔DDD mode without rate response;
2: backup rate at 60 bpm and synchronous upper rate at 130 bpm; while rate response was not programmed the maximum rate response corresponded to the sensor-driven rate in case of mode switch for atrial arrhythmia (fallback in DDIR mode);
3: the MVP mode functions properly with nearly 100% of spontaneous ventricular events;
4: the long-term atrial histogram showed the absence of rate responsiveness and chronotropic insufficiency in this active patient; the atrial rate remains between 60 and 70 bpm throughout the follow-up;
5: the long-term ventricular histogram also shows this rate limitation; the ventricular events are spontaneous;

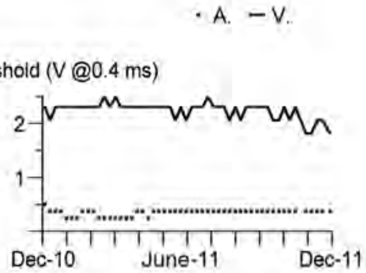
Comments

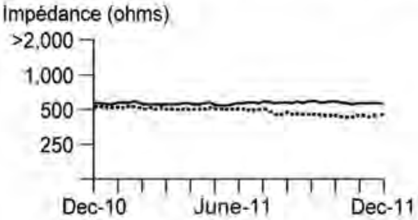
This first page of initial interrogation enables a nearly complete evaluation of the important components of the patient's follow-up: 1) there are no signs of battery depletion, and the remaining longevity is estimated at > 7 years; 2) both leads are functioning satisfactorily (pacing and sensing impedance within normal limits) despite a ventricular pacing threshold slightly elevated; 3) the pacemaker is programmed in AAI⇔DDD mode; the rate response corresponds to an automatic rate responsiveness during mode switch; 4) the section "% of total pacing" provides an analysis of the patient's conduction status in percentage of time elapsed since a last interrogation, during which the device paced or sensed during the sampling period. The percentages are calculated from the daily counts of AS-VS, AS-VP, AP-VS and AP-VP sequences of events. The percentages of ventricular sensing approach 100%, confirming the proper function of the MVP mode and the usefulness of its implementation; 5) the long-term atrial and ventricular histograms can be used to diagnose chronotropic insufficiency. The rate histograms show the percentage of time spent by the device in pacing and sensing in the various rate ranges, which, in this pacemaker model, total 16, each 10 bpm long. Rates below 40 bpm are included in the range "<40" and rates above 180 bpm are included in the range ">180". In this active patient, the rate varies little and is mostly clustered near the lowest values. A physiologic increase in heart rate contributes to the increase in cardiac output during exercise; while the dyspnea experienced by this patient might be multifactorial, it might be explained, in part, by the imbalance caused by the metabolic requirements related to the on-going exercise and the absence of changes in heart rate. In this patient, this chronotropic insufficiency must be corrected by the programming of rate responsiveness and the AAIR⇔DDDR pacing mode.

Initial Interrogation Report

Device: Medtronic Adapta ADDR01

Pacemaker Status (Implanted: 23.00.00)





Battery Status

Estimated remaining longivity : Basd on Past History	7 years, 6 - 8.5 years
Voltage/Impédance	2.77 V / 295 ohms

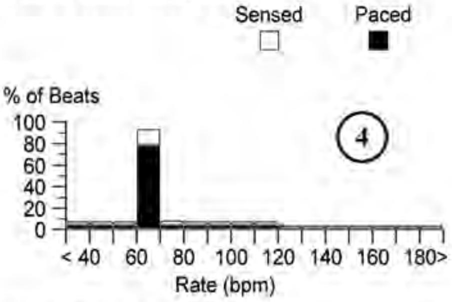
Lead Summary	**Atrial**	**Ventricular**
Measured Threshold	0.375 V à 0.40 ms	1.375 V à 0.40 ms
Date0 Measured	12.00.00	11.00.00
Programmed Ouput	1.500 V / 0.40 ms	3.750 V / 0.40 ms
Capture	Auto	Auto
Measured P/R Wave	>2.8 mV	16.0 à >22.4 mV
Programmed Sensivity	0.50 mV	5.60 mV
Measured Impedance	443 ohms	569 ohms
Lead Status	OK	OK
Lead Model Implanted		

Parameter Summary

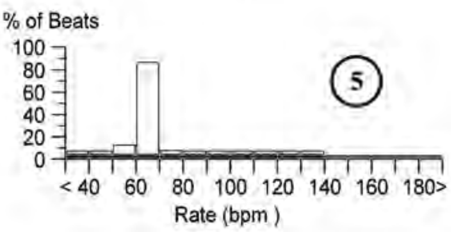
Mode	AAI<=>DDD	(1)	Lower Rate	60 bpm		Paced AV	150 ms
Mode switch	On		Upper Tracking Rate	130 bpm	(2)	Sensed AV	120 ms
Detection Rate	175 min-¹		Upper Sensor Rate	130 bpm			

Clinical Status : 16.07.09 to 12.12.11

Atrial Long Term Histogram



Ventricular Long Term Histogram



Mode Switches : 1 (% of time : < 0.1%)
Atrial High Rate Episodes : 0
Episode Trigger : Mode switch > 30 sec
Ventricular Hight Rate Episodes : 0

Pacing (% of total)	
AS - VS	20.6%
AS - VP	0.2%
AP - VS	78.6%
AP - VP	0.6%
MVP	On

(3)

Event Counters	
PVC singles	386,584
PVC runs	1,285
PAC runs	62

 Page 1

Case 3: Proper Chronotropic function

Patient

This asymptomatic 75-year-old woman underwent implantation of an Adapta pacemaker for complete AV block after surgical treatment of the aortic valve; she was seen for a routine follow-up, 3 months after device implantation.

EGM

1: programming in AAI⇔DDD mode without rate response;
2: nearly incessant ventricular pacing; low percentage of atrial pacing; this pacemaker-dependent patient presents with late ventricular extrasystoles, which might explain the 1.1% of AS-VS;
3: the long-term atrial histogram shows a nearly totally intrinsic atrial rhythm and a satisfactory rate distribution;
4: the ventricles are paced; the curve of ventricular rate is similar to that of the atrial rate;

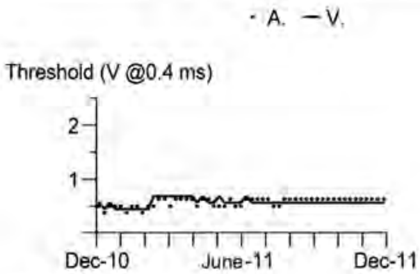
Comments

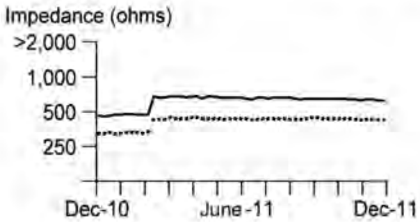
As in the previous report, this first page enables the verification of the system's proper function (no signs of depletion, proper function of both leads; as the patient seems pacemaker-dependent, sensing could not be tested). The device is also programmed in AAI⇔DDD mode. However, these histograms are dissimilar from the previous case:
1) the percentage of ventricular pacing approached 100%. This observation is not surprising, since aortic valve surgery is often the cause of permanent injury to the AV conduction pathway. A recovery of normal conduction several months after the operation seemed highly improbable. Therefore, the programming of the AAI⇔DDD mode must be reconsidered. Every 16 hours, the device determined the presence of AV conduction, resulting in a single missing cycle, which could be avoided by reprogramming the device to DDD mode; 2) the distribution of atrial rates was satisfactory, with evidence of a preserved chronotropic function. Therefore, programming of rate responsiveness in this patient was unnecessary, and the rate acceleration could rely strictly on the acceleration of sinus rhythm, the most physiologic and best reflection of the patient's physiological needs.

Initial Interrogation Report

Device: Medtronic Adapta ADDR01

Pacemaker Status (Implanted: 23.00.00)





Battery Status

Estimated remaining longivity : Basd on Past History	9 years, 7.5 - 10.5 years
Voltage/Impédance	2.78 V / 270 ohms

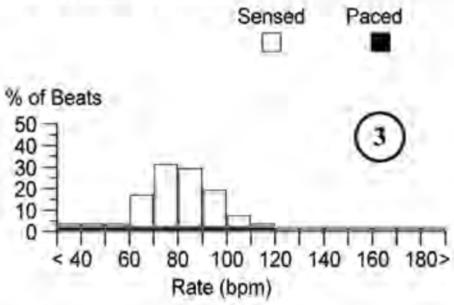
Lead Summary	Atrial	Ventricular
Measured Threshold	0.625 V à 0.40 ms	0.500 V à 0.40 ms
Date Measured	00.00.00	00.00.00
Programmed Ouput	1.500 V / 0.40 ms	2.000 V / 0.40 ms
Capture	Auto	Auto
Measured P/R Wave	>2.8 mV	> = à 80 % paced
Programmed Sensivity	0.50 mV	2.80 mV
Impédance mesurée	427 ohms	656 ohms
Lead Status	OK	OK
Lead Model Implanted		

Parameter Summary

Mode	AAI<=>DDD	(1)	Lower Rate	60 bpm	Paced AV	150 ms
Mode switch	On		Upper Tracking Rate	130 bpm	Sensed AV	120 ms
Detection Rate	175 bpm		Upper Sensor Rate	130 bpm		

Clinical Status : 17.11.11 à 12.12.11

Atrial Long term Histogram



Mode Switches : 1 (% du Temps : < 0.1%)

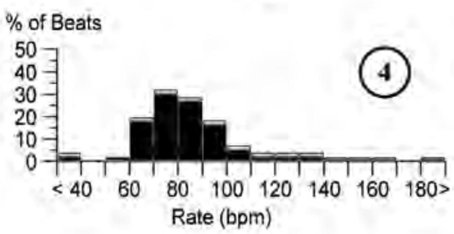
Atrial Hight Rate Episodes: 0

Episode TRigger : Mode Switch > 30 sec

Ventricular Hight Rate Episodes: 0

Pacing (% of total)			Events Counters	
AS - VS	1.1%	(2)	PVC Singles	52,522
AS - VP	96.5%		PVC runs	34
AP - VS	< 0.1%		PAC runs	0
AP - VP	2.4%			
MVP	Marche			

Histogramme ventriculaire long terme



Case 4: Automatic rate Responsiveness after mode switch

Patient

This 64-year-old asymptomatic man with grade II mitral insufficiency received an Adapta pacemaker for treatment of complete AV block; he underwent routine follow-up.

EGM

1: programming in DDD mode without rate response;
2: the atrial histogram indicates a transition to persistent AF;
3: the ventricular histogram shows rate responsive pacing with a satisfactory distribution of the rate ranges;

Comments

This patient's device was initially programmed in DDD mode without rate response. The atrial histogram reveals the presence of very high atrial rates which correlate with AF (confirmed on the surface ECG). The pacemaker switched to DDIR mode, explaining the ventricular histogram, which showed a satisfactory rate response (a switch to DDI mode, in this patient, would have caused fixed pacing at the slowest rate).

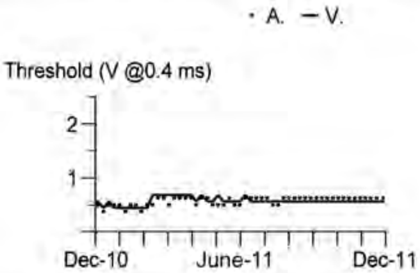
This pacemaker interrogation raises several questions:

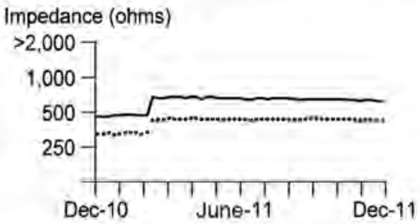
1) this patient presented with a 2 to 3 CHADS score and was a candidate for anticoagulation. The heart rate was well controlled because of her conduction disorder, she was asymptomatic and the diagnosis of AF was made during a routine visit. A systematic remote follow-up by telemedicine should allow a much earlier diagnosis in asymptomatic patients; 2) a conversion of the atrial arrhythmia to sinus rhythm might be considered even if the patient is asymptomatic and the heart rate is well controlled; 3) should a strategy of conversion to sinus rhythm be favored, DDD with switch to DDIR mode in presence of an atrial arrhythmia seems preferable. In this patient, the merits of rate responsiveness during fallbacks are apparent, with preservation of appropriate rates at rest as well as during exercise. Should a strategy of rate control be favored, the presence of permanent AF would probably justify the programming of VVIR mode.

Initial Interrogation Report

Device: Medtronic Adapta ADDR01

Pacemaker Status (Implanted: 23.00.00)





Battery Status

Estimated remaining longivity : Basd on Past History	9 years, 7.5 - 10.5 years
Voltage/Impédance	2.78 V / 270 ohms

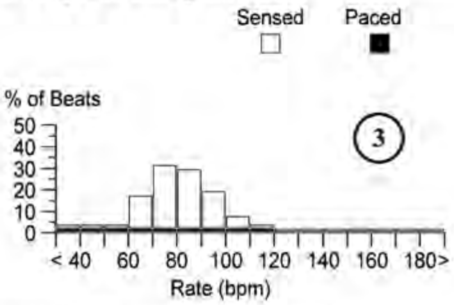
Lead Summary	Atrial	Ventricular
Measured Threshold	0.625 V à 0.40 ms	0.500 V à 0.40 ms
Date Measured	00.00.00	00.00.00
Programmed Ouput	1.500 V / 0.40 ms	2.000 V / 0.40 ms
Capture	Auto	Auto
Measured P/R Wave	>2.8 mV	> = à 80 % paced
Programmed Sensivity	0.50 mV	2.80 mV
Impédance mesurée	427 ohms	656 ohms
Lead Status	OK	OK
Lead Model Implanted		

Parameter Summary

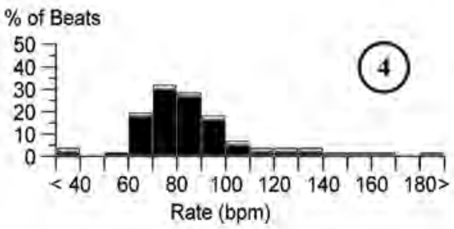
Mode	AAI<=>DDD	(1)	Lower Rate	60 bpm	Paced AV	150 ms
Mode switch	On		Upper Tracking Rate	130 bpm	Sensed AV	120 ms
Detection Rate	175 bpm		Upper Sensor Rate	130 bpm		

Clinical Status : 17.11.11 à 12.12.11

Atrial Long term Histogram



Histogramme ventriculaire long terme



Mode Switches : 1 (% du Temps : < 0.1%)
Atrial Hight Rate Episodes: 0
Episode TRigger : Mode Switch > 30 sec
Ventricular Hight Rate Episodes: 0

Pacing (% of total)		
AS - VS	1.1%	(2)
AS - VP	96.5%	
AP - VS	< 0.1%	
AP - VP	2.4%	
MVP	Marche	

Events Counters	
PVC Singles	52,522
PVC runs	34
PAC runs	0

Case 5: Competition between sinus acceleration and rate response by the pacemaker

Patient

This 75-year-old man underwent implantation of an Ensura dual chamber pacemaker for complete AV block, programmed in DDDR mode; the pacemaker was interrogated.

EGM

1: satisfactory distribution of atrial rates on this histogram, which shows an acceleration of the spontaneous atrial rhythm competing with the paced rate responsive rhythm;
2: appropriate ventricular rate curve with paced ventricles;

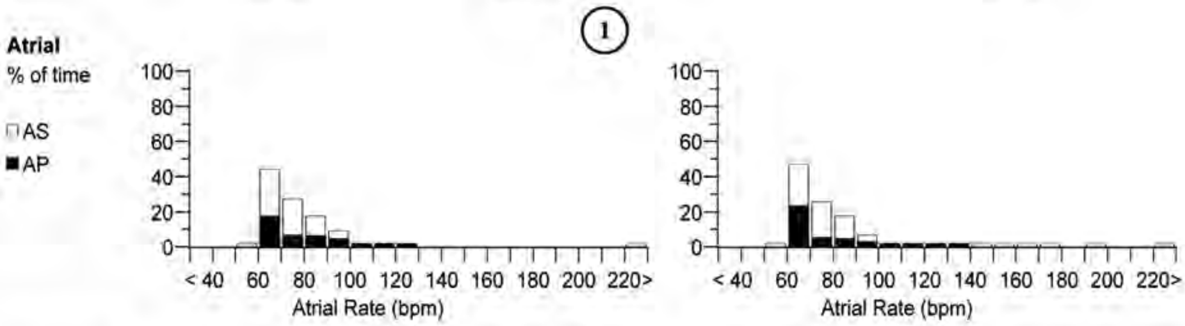
Comments

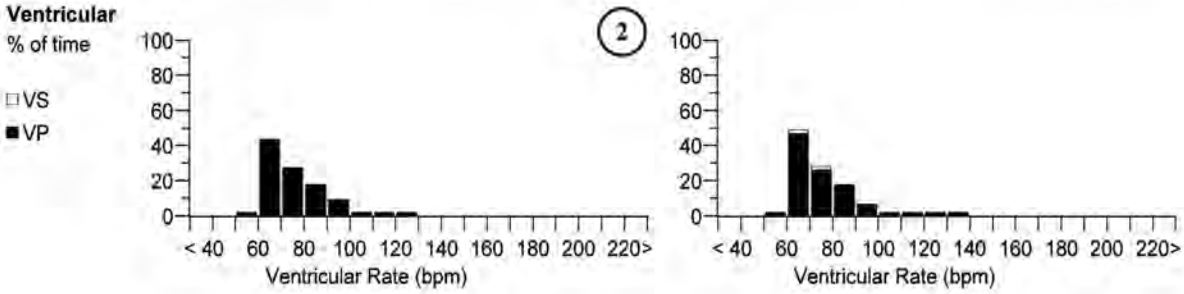
Rate responsiveness must be programmed for chronotropic insufficiency. Without it, an unnecessary competition takes place between paced and spontaneous rhythms. Normal sinus rhythm is the best indicator of the physiologic metabolic demand. Rate responsiveness is an additional factor of energy consumption. Consequently, it seems appropriate, in this patient, to eliminate the rate response and reprogram the device to DDD mode.

Initial Interrogation : Histogram of Rate.

Device : **Ensura DR MRI EN1DR01**

		Previous Last Session 15-Nov-0000 au 12-Dec-0000 27 Days	Last Session 12-Dec-0000 au 15-May-0000 5 months
% of Time	**Total of VP**	100.0 %	100.0 %
	AS-VS	< 0.1%	< 0.1%
	AS-VP	63.6 %	61.9 %
	AP-VS	< 0.1%	< 0.1%
	AP-VP	36.4 %	38.1 %





Case 6: 2:1 point on exercise

Patient

28-year-old woman who underwent surgical implantation of a triple chamber pacemaker (1 atrial lead, 2 left ventricular leads) for congenital complete AV block; device programmed in DDD mode (1 left ventricular lead) at 60-120 bpm; she complained of exercise-induced dyspnea; she underwent exercise testing (repetitive flexing of the legs) with the telemetry head positioned over the pulse generator; the EGM were recorded during vigorous effort with, from one cycle to the next, a sensation of dyspnea (exercise was discontinued at this very moment to obtain a recording of high quality).

EGM

Tracing 6a: vigorous effort;

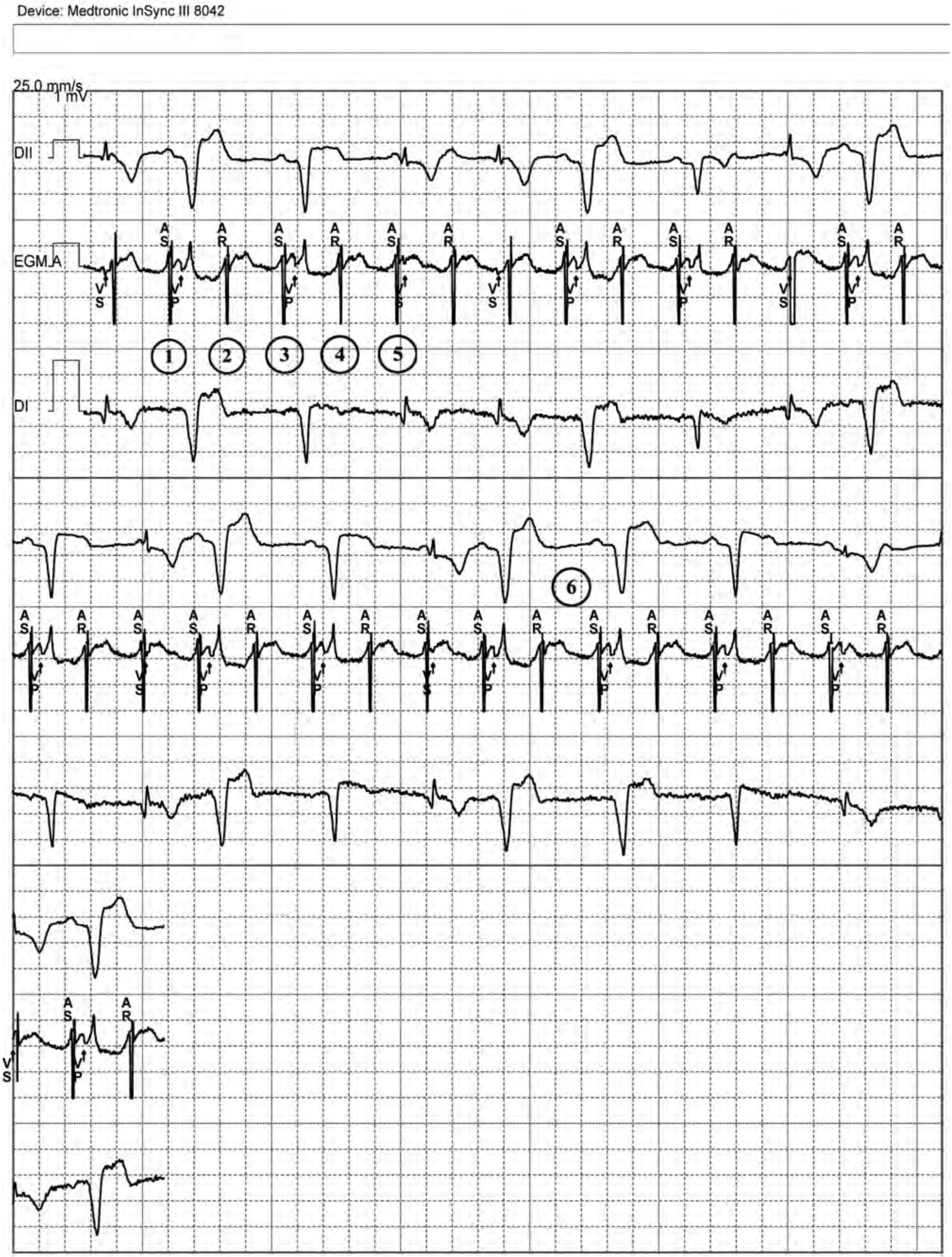
1: AS-VP cycle at the programmed AV delay;
2: blocked sinus P wave because falling during the PVARP (AR);
3: new AS-VP cycle at the programmed AV delay;
4: blocked sinus P wave falling in the PVARP (AR); 2:1 block;
5: a sudden fall in heart rate favors the emergence of a junctional escape rhythm (narrow QRS, VS immediately after AS); AV dissociation;
6: this explains why the next sinus P wave is AR;
7: a ventricular junctional cycle appears again (VS); a dissociated sinus P wave immediately after VS, is not sensed by the pacemaker because it fell in the programmed, absolute, post-ventricular atrial blanking period and, therefore, is not labeled Ab;
8: repetition of 2:1 cycles alternating with junctional escapes;

Tracing 6b: tracing recorded during recovery;

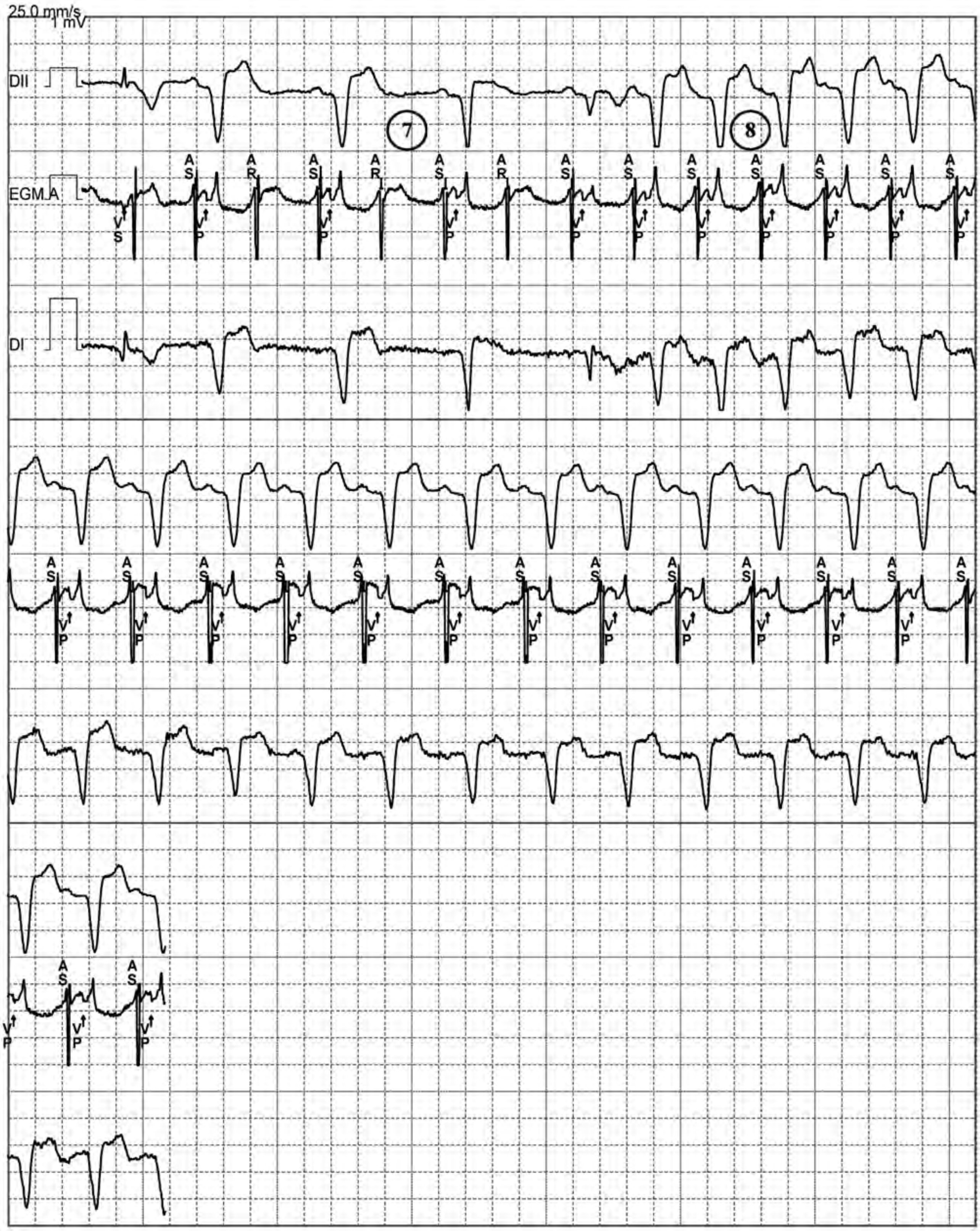
9: 2:1 block with sensed P wave (AS) alternating with a blocked P wave (AR) falling in the refractory period;
10: slowing of sinus rate during recovery and return of 1:1 AS-VP cycles.

Comments

This tracing highlights the specific observations made in young pacemaker recipients, whose physical activity and cardiac mechanical function are preserved:
1) the pacing site is key in these young patients in complete AV block who are incessantly paced for many years. Left ventricular pacing might be less detrimental than right ventricular pacing from the standpoint of remodeling and ventricular function; 2) similarly, the device programming must be adapted to the specific characteristics of these patients. In this patient, the 2:1 point was set much too low, a setting that was responsible for her symptoms. The sensed AV delay was programmed à 160 ms without being adaptive and the PVARP was programmed at 350 ms without automatic shortening when the rate accelerated. The sum of these 2 atrial refractory periods defined a 2:1 point below 120 bpm, i.e. much below the actual performance of the patient. The total atrial refractory period, which defines the 2:1 point, corresponds to the sum of the AV delay + PVARP.


Device: Medtronic InSync III 8042
25.0 mm/s
1 mV
DII
EGM A
DI
1
2
3
4
5
6
A S
A R
V S
V P

Device: Medtronic InSync III 8042



Case 7: Pseudo-Wenckebach behavior during effort

Patient

Same patient as on the preceding tracing; programming change with decrease in the maximal value of the PVARP, and programming of an automatic adaptation of the PVARP and adaptive AV delay; new exercise test with attenuation of the feeling of limitation than during the previous test.

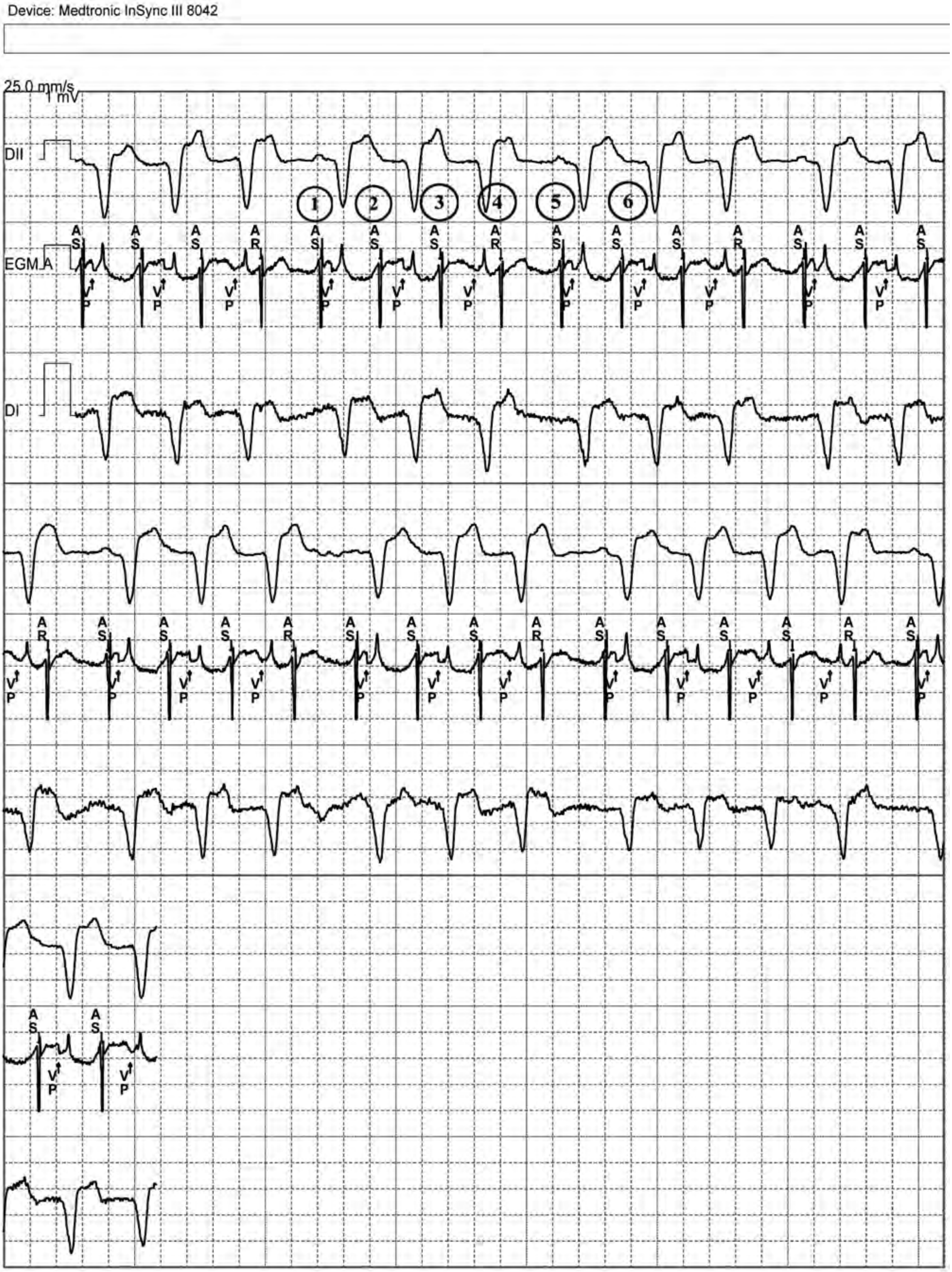
EGM

The first channel is lead II of the surface ECG, the second is the atrial EGM with the superimposed markers, and the third channel is lead I;

1: AS-VP cycle with programmed AV delay;
2: AS-VP cycle with prolongation of the AV delay to respect the 120-bpm maximum rate;
3: Wenckebach function with yet more marked prolongation of the AV delay;
4: blocked P wave (AR) falling in the PVARP and initiating neither an AV delay nor ventricular pacing;
5: resumption of AV synchrony with short AV delay;
6: continuation of 4:3 pseudo-Wenckebach function;

Comments

Exercise testing is an important step in the follow-up of pacemaker recipients, particularly when symptomatic. It should preferably be performed while analyzing the EGM during exercise, using the programmer, with a view to detect a possible dysfunction and perhaps reprogram the device in real time, depending on the observations that were made. Exercise might consist of a simple walk to mimic the efforts of daily life. Repetitive flexing of the legs emulates a more vigorous effort. These 2 types of exercise tests are of practical interest as they can be performed at the time of the follow-up visits. A standard bicycle exercise test offers the advantage of a continuous 12-lead electrocardiographic follow-up. Another value of the test is the verification of the appropriateness of a programming change. In this patient, the shortening of the AV delay and PVARP allowed a relocation of the 2:1 point to a better adapted rate of 180 bpm. On the other hand, persistence of an upper triggered rate at 120 bpm explains the Wenckebach function observed on this tracing. In this patient, the periodicity of the pseudo-Wenckebach function was 4:3. With this programming, pseudo-Wenckebach periodicity was observed in this patient for sinus rates between programmed upper rate (120 bpm) and 2:1 point (180 bpm). An increase in sinus rate would increase the proportion of blocked P waves. There was no reason to curb the maximum triggered rate in this young, active patient free from structural heart disease. A reprogramming of the maximum synchronous rate to 180 bpm enabled a consistent atrial tracking over this patient's entire range of rates, at rest as well as during maximum effort.


Device: Medtronic InSync III 8042
25.0 mm/s
1 mV
DII
EGM A
DI
1
2
3
4
5
6
AS
AR
VP

Case 8: Prolonged PR during exercise

Patient

This 56-year-old patient complaining of dyspnea during exercise and a history of syncopal events underwent implantation of an Adapta dual chamber pacemaker and programmed to a 320-ms PR interval at rest; an episode of rapid ventricular rate was recorded in the device memory.

EGM

Tracing 8a:

1: programming in AAIR⇔DDDR mode;

2: recorded 4 minute episode of rapid ventricular rate with AV dissociation (atrial rate at 64 bpm, ventricular rate at 151 bpm);

3: the rate histogram showed a tachycardia at 150 bpm.

Tracing 8b:

4: the EGM channel shows simultaneous ventricular and atrial signals; the atrial signal was not sensed because it fell in the post-ventricular atrial blanking period; the episode was, thus, labeled "ventricular high rate" when the latter surpassed 150 bpm;

Comments

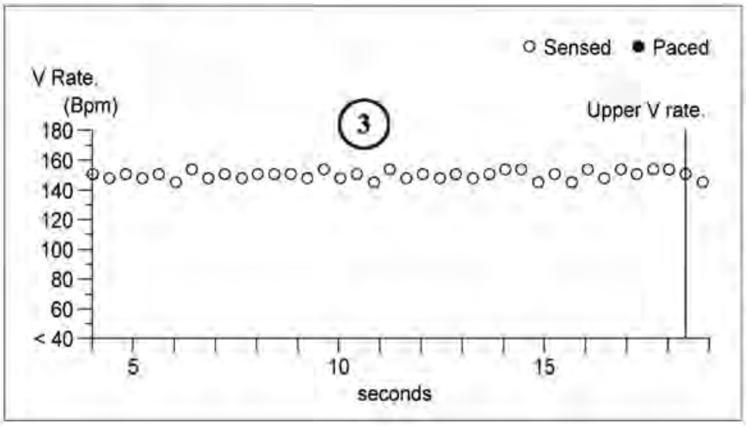
The tracings stored in the devices' memories must be verified. This episode was erroneously labeled by the pacemaker as a rapid ventricular event. Analysis of the EGM suggests that it was a sinus tachycardia in this patient with a long PR interval. This tracing was obtained during effort. The P wave was not sensed as it fell inside the post-ventricular atrial blanking period.

The MVP mode confers a sizable benefit, mainly in patients in sinus rhythm, by markedly decreasing the percentage of ventricular pacing. Its indication is less clear in patients with a long PR interval, particularly if it does not shorten with exercise. It is possible that the exercise-induced dyspnea was entirely or in part due to this prolonged PR interval during effort, from a mechanism similar to the pacemaker syndrome, as a result of simultaneous contraction of the atria and ventricles. Programming to the DDD mode is probably more appropriate for this patient. One could verify the merit of this programming change by comparing the symptoms experienced by this patient during exercise tests performed in MVP and in DDD modes.

Hight Rate Ventricular Episode

Device: Medtronic Adapta ADDR03

Zoom - Onset Collected - 10.03...



Initial Interrogation

Mode	AAIR<=>DDDR
Lower rate	60 bpm
Upper Tracking Rate	140 bpm
Upper sensor Rate	130 bpm
Detection rate	150 bpm
Detection duration	5 cycles

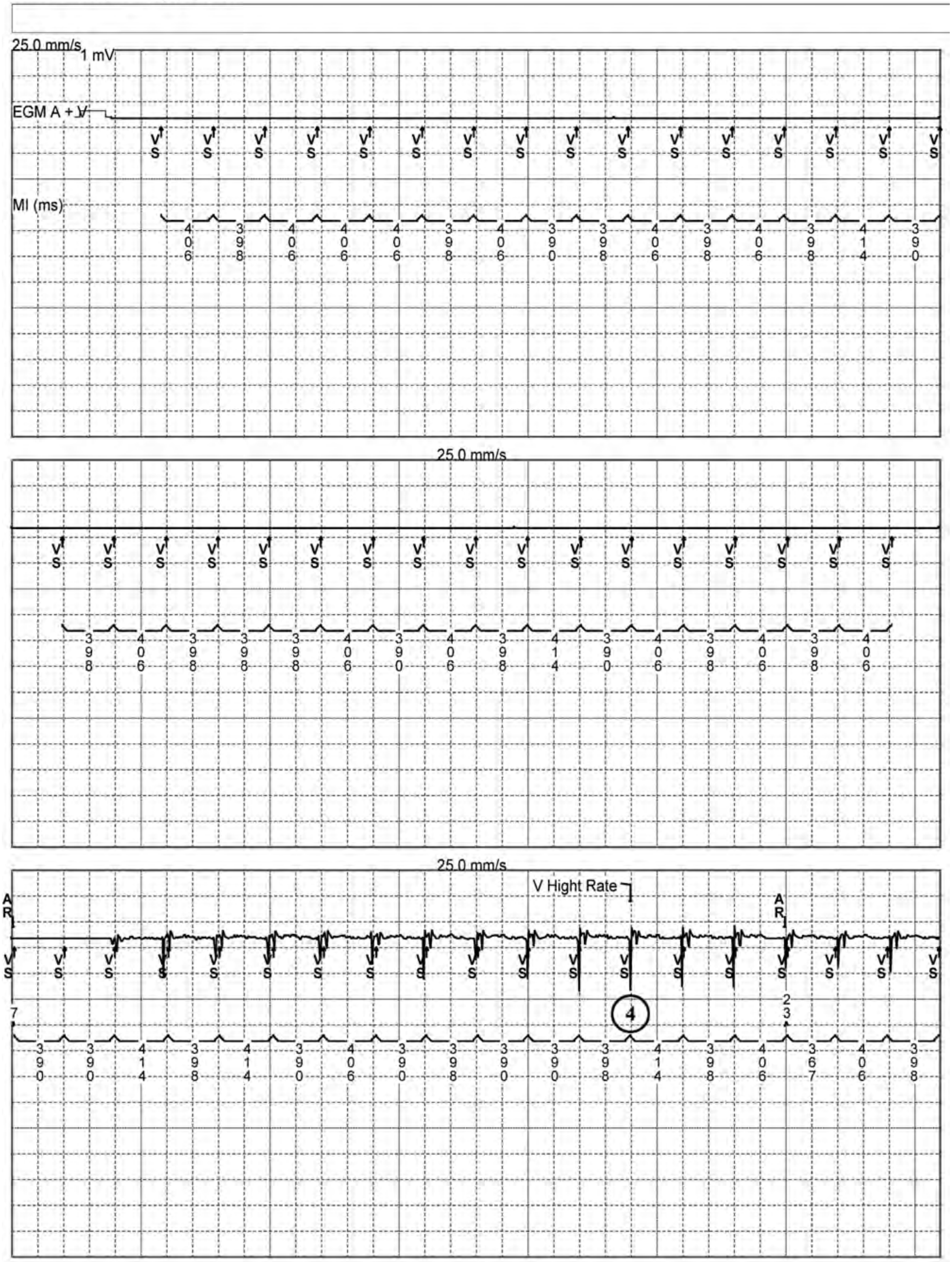
(1)

Episodes Data

Duration (hh:mm:ss)	00:00:04
Max A rate	64 bpm
Max V rate	151 bpm

(2)

Device: Medtronic Adapta ADDR03



Pacing & Arrhythmias

Cardiac pacemaker and management of atrial arrhythmias

General points

The management of cardiac pacemaker recipients who present with episodes of atrial arrhythmias is complex because of the risk of run away of ventricular pacing by tracking of a rapid atrial rhythm. From a continuous analysis of the atrial rhythm, mode switch causes the automatic transition from an atrial tracking DDD or VDD, to a non-atrial tracking DDI pacing mode. The fallback algorithm prevents ventricular pacing at high rates, synchronized to the rates of atrial arrhythmias. An ideal mode switch algorithm combines the following characteristics:

- rapid onset to avoid rapid ventricular pacing during the initial phase of sensing of the arrhythmia
- ability to return rapidly to a synchronous mode at the end of the arrhythmic episode
- high diagnostic accuracy of atrial arrhythmias despite the presence of atrial electrograms of variable rate and amplitude
- capable of avoiding mode switch in response to far-field sensing, noise or sinus tachycardia

The pacemaker automatically records the diagnostic data of the various arrhythmic episodes to assist in the management of these patients and, perhaps, modify their treatment.

Some additional algorithms serve to prevent arrhythmias and can be programmed to prevent pacing in the vulnerable period, or to pace rapidly to counteract the mechanisms promoting the onset of atrial tachyarrhythmias:

- non-competitive atrial pacing prevents the trigger of an atrial arrhythmia, which might be caused by pacing in the atrial relative refractory period following an atrial extrasystole, by observing a minimum escape interval after the extrasystole;
- stabilization of the atrial rhythm adapts the pacing rate in response to an atrial extrasystole to eliminate long sinus pauses following short cycles;
- atrial preference pacing forces a continuous atrial pacing slightly faster than the spontaneous rhythm;
- post-mode switch overdrive pacing can be added to the mode switch function to pace the atrium rapidly when DDD mode returns after the end of an atrial arrhythmic episode;
- the "conducted AF response" regularizes the ventricular rate during episodes of atrial fibrillation, thus preventing prolonged pauses.

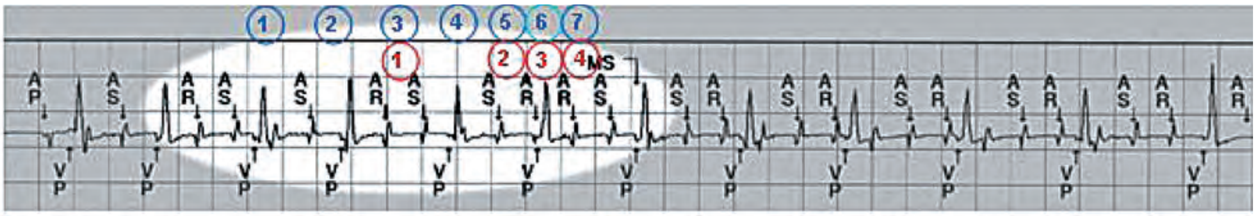
Automatic mode switch for atrial arrhythmias

Mode switch is an ON / OFF programmable function designed to prevent the tracking of paroxysmal atrial tachycardias when the pacemaker operates in DDD, VDD or MVP modes.

Mode switch to non-atrial tracking mode (DDD to DDIR)

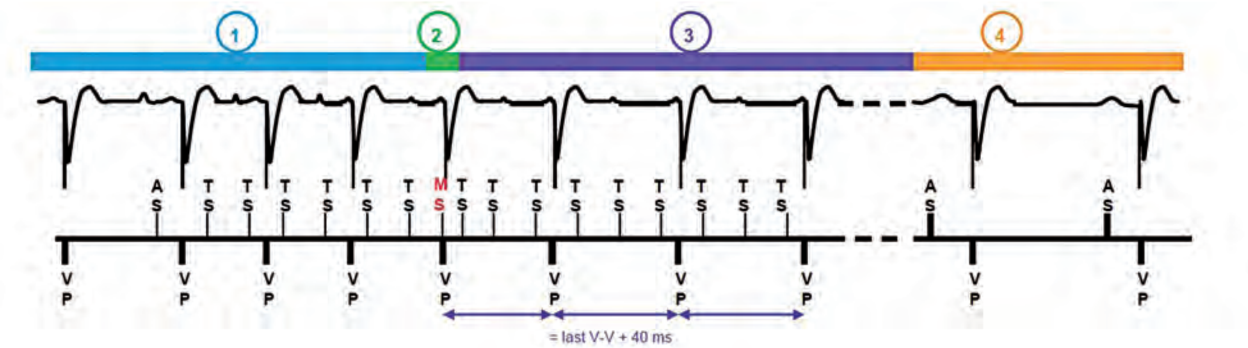
The criteria prompting a switch from an atrial synchronous to DDIR mode vary among the range of implanted pacemakers. In the Adapta series, the pacemakers switch to DDIR mode when:

- out of 7 consecutive atrial intervals (AS-AR or AR-AS), 4 are shorter than the programmed detect rate interval.



In the Advisa / Ensura series the pacemaker switches to DDIR mode when 1 or both the following conditions is (are) met:

- the median of 12 consecutive atrial intervals is shorter than the programmed AT/AF interval.
- The AT/AF counter is ≥3. The AT/AF counter of is incremented by 1 point, each time ≥2 atrial events are sensed between 2 ventricular sensed or paced events.



1. Onset of atrial arrhythmia in a patient in complete AV block, programmed in DDD mode. Each AS event is followed by a ventricular paced event: acceleration of the pacing rate.
2. The AT/AF counter = 3 (3 VP-VP cycles with at least 2 sensed atrial events): mode switch to DDIR (MS).
3. Gradual slowing of the tracking rate to the rate responsive rate (+ 40 ms with each interval)
4. End of arrhythmia. Return to the programmed mode (except for the MVP mode with which there is invariably a return to DDD preceding the return to AAI)

Mode switch to atrial tracking (DDIR to DDD or VDD)

The criteria which lead to the switch from DDIR to the atrial synchronous mode also vary depending on the series of pacemakers implanted.
With the Adapta models, the pacemaker switches to the atrial tracking mode:

- if the last 7 A-A intervals are longer than the maximum synchronous rate interval, or if 5 atrial pacing events occur.

With the Advisa / Ensura series, the pacemaker switches to the atrial tracking mode if 1 of the following criteria is met:

- identification of normal sinus rhythm (or normal paced rhythm) for 5 consecutive ventricular intervals
- the median atrial cycle is longer than the AT/AF sensing cycle
- the AT/AF counter is <27 for 3 min.

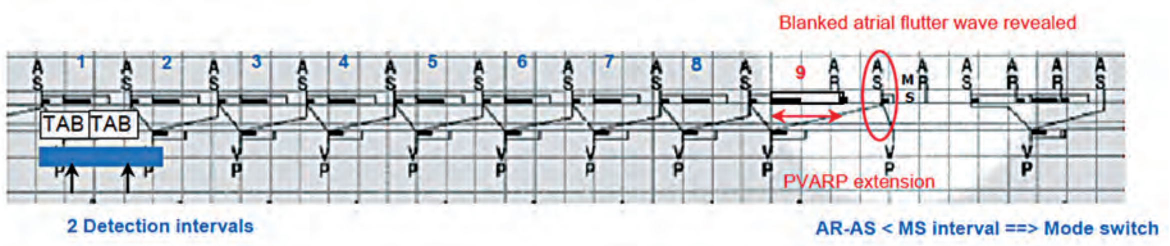
In both series, the ventricular pacing rate switches from sensor-indicated to atrial tracking.

Blanked flutter search

The mode switch algorithm has a programmable blanked flutter search setting based on the detection of short atrial cycles occurring on a 2:1 basis in the PVAB. Atrial flutter is a perfectly regular arrhythmia. Depending on its rate and on the setting of the AV delay, 1 out of 2 atrial events may fall in the PVAB. Consequently, 1 out of 2 flutter waves is labeled AS and is followed by pacing, while the other atrial event falls in the PVAB and is neither sensed nor counted by the device. This may continue and cause a prolonged, rapid ventricular paced rhythm without diagnosis of flutter. The algorithm of blanked flutter search is activated when 8 consecutive AS-AS intervals are:

- shorter than twice the sum of the AV delay + the PVAB;
- shorter than twice the programmed interval of atrial arrhythmias detection.

If these 2 conditions are met, the device suspects the presence of blanked flutter and extends the PVARP of the next cycle to unmask the next atrial event (AR) in the refractory period, suppress ventricular pacing and uncover the next flutter wave (AS).



Memorization of atrial arrhythmia episodes

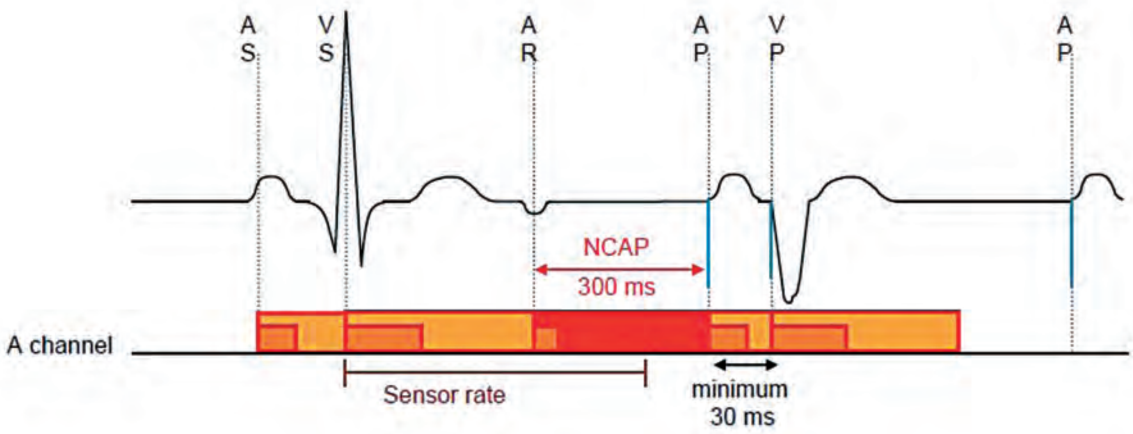
Pathologic atrial events are memorized when they cause fallback. Fallback and memorization are, therefore, coupled.

Other specific algorithms of atrial arrhythmias management

Non-competitive atrial pacing (NCAP)

Aim: to prevent the triggering of an atrial tachyarrhythmia by an atrial pacing stimulus that falls within the atrium's vulnerable period.

Operation: when NCAP is programmed ON, a sensed atrial refractory event falling in the PVARP starts a programmable NCAP during which no atrial pacing may occur. If a sensor-driven or a lower rate pacing stimulus is scheduled to occur during the NCAP, the VA interval is extended until the NCAP expires.
If no pacing stimulus is scheduled to occur during the NCAP, the timing is unaffected and pacing occurs at the end of the VA interval, unless inhibited. An atrial refractory sensed event occurring during the NCAP starts a new NCAP.
When an atrial pacing stimulus is delayed by the NCAP operation, the pacemaker attempts to maintain a stable ventricular rate by shortening the paced AV delay that follows, down to a minimum of 30 ms. The paced AV delay, however, will not be shortened beyond 30 ms. The NCAP interval is 400 ms for 1 paced cycle each time a PVC response or an anti-PMT intervention occurs. This function is available when the pacemaker operates in DDD, DDI, or MVP (AAI<=>DDD) modes.



Atrial preference pacing

Aim: Atrial preference pacing (APP) is designed to lower the incidence of atrial tachyarrhythmias by forcing atrial pacing at a rate slightly higher than the spontaneous rhythm.

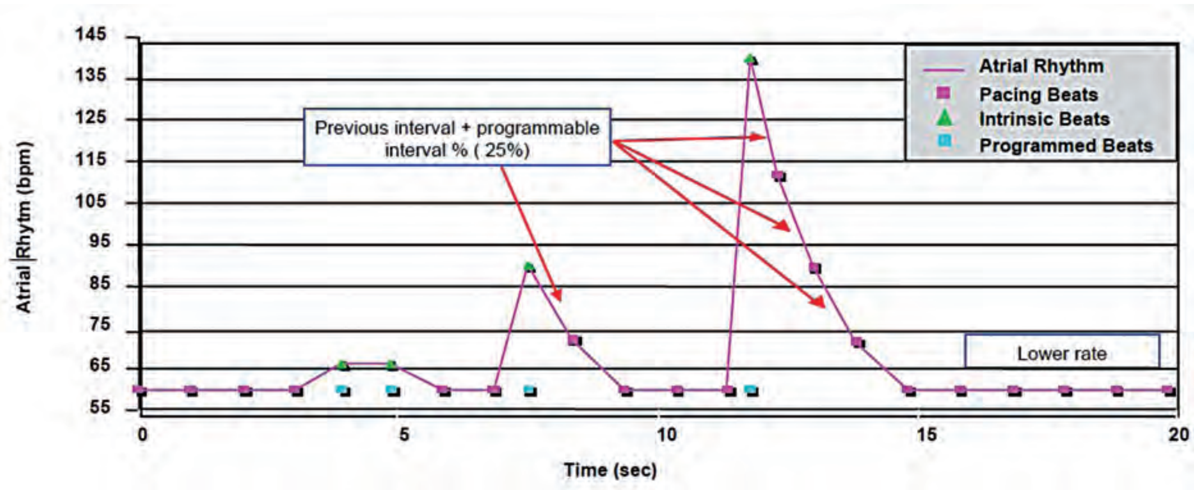
Operation: the device responds to variations in the atrial rate by accelerating the pacing rate until it reaches a stable paced rhythm that is slightly faster than the spontaneous rate. After each sensed, non-refractory atrial event, the device shortens the atrial pacing interval by a programmed decremental value. If the next atrial event is another non-refractory sensed event, the pacing interval is further decremented. This overdriving function continues until the pacing rate surpasses the spontaneous rate, resulting in a paced atrial rhythm. However, the programmed upper rate provides a limit to the APP rate. After a programmable period of atrial pacing at 100%, the pacemaker gradually decreases the pacing rate, like a smoothing function, in search of the next spontaneous sinus cycle, which restarts the APP.

A long decremental interval causes a more aggressive response to a sinus rate increase, which means that APP occurs more often, more rapidly and lasts longer than with a shorter decremental interval. Conversely, a shorter interval attenuates the response to isolated atrial extrasystoles and sinus variability near the lower rate. APP reacts more slowly to a sustained increase in rate.
APP is available when the pacemaker operates in DDD, AAI or MVP mode.
The atrial pacing pulses delivered by APP are labeled PP (proactive pacing) on the event markers.

Atrial rhythm stabilization (limited to the Advisa series)

Aim: atrial rhythm stabilization (ARS) is a programmable function designed to prevent long sinus pauses, which usually follow atrial extrasystoles. Short-long-short cycle sequences can be arrhythmogenic and facilitate the onset of atrial tachyarrhythmias.

Operation: when activated by the sensing of an atrial extrasystole, the device delivers a pacing pulse at the premature interval, increased by a percentage of that interval (defined by a programmed Interval Percentage Increment parameter). The atrial pacing rate is then gradually decreased until the return of the spontaneous rate, the programmed pacing rate or the sensor rate. The Maximum Rate parameter sets an upper rate limit for ARS.
ARS is available when the device operates in DDD, AAI or MVP (AAI<=>DDD) mode.
The atrial pacing pulses delivered for ARS are labeled PP (proactive pacing) on the event markers.



Post mode switch overdrive pacing (Adapta and Advisa series)

Aim: post mode switch overdrive pacing (PMOP) can be added to the mode switch function to pace the atria rapidly after the cessation of an episode of atrial tachyarrhythmia. The emergence of a slow heart rate after the end of an arrhythmia is associated with an increased risk of very early recurrence.

Operation: after the return of sinus rhythm and switch to DDD/VDD mode, the device increases the pacing rate beat-by-beat (decreasing the pacing interval by 15 ms per pulse for Adapta and 70 ms for Advisa) until it reaches the programmed Overdrive Rate. It then smooths the return to the programmed atrial tracking mode by gradually slowing the rate until reaching the programmed pacing rate, the lower programmed rate or the sensor rate.
PMOP is available when the device operates in DDD or MVP (AAI<=>DDD) mode.

Response to conducted AF (Adapta and Advisa series)

Aim: the response to conducted AF is an algorithm designed to promote a regular ventricular rate during episodes of AF to prevent long diastoles.

Operation: during an episode of AF, the pacemaker modifies the beat-by-beat pacing rate in order to pace near the mean intrinsic ventricular rate. This eliminates long pauses and diminishes the irregularity of the ventricular rate. The response to conducted AF function adjusts the pacing rate, such that it is faster in presence of sensed ventricular events and slower in presence of ventricular pacing pulses. The increase in pacing rate caused by the response to conducted AF is limited by the programmed maximum rate. Depending on the programmed response level value (a higher response level value results in a higher percentage of ventricular pacing and faster alignment with the patient's own ventricular response rate), the device accelerates the pacing rate in response to a sensed event and slows the pacing rate in response to a pacing pulse.

Case 1: Mode switch during an episode of AF

Patient

Same patient as for tracing 1 of pacing mode chapter; the patient is in AV block; he underwent pacemaker interrogation 3 days after device implantation; programming of various pacing modes and recording of the tracings; DDD mode programming.

EGM

Tracing 1a: the first channel is lead I of the surface ECG with the markers superimposed, the second shows the time intervals, the third is lead III and the last channel is lead II;

1: atrial and ventricular paced rhythm (AP-VP);
2: atrial extrasystole outside the refractory period with ventricular pacing (AS-VP);
3: another atrial extrasystole;
4: acceleration and disorganization of the atrial rhythm; the atrial events labeled AS are conducted to the ventricle, the atrial events in the refractory period (AR) are blocked;
5: mode switch (MS); indeed, out of the 7 previous consecutive atrial intervals, at least 4 are shorter than the programmed interval of rate detection;
6: slowing of the paced ventricular rate after switch to DDIR mode;

Tracing 1b: the episode of AF lasted 2 minutes before spontaneous conversion; new tracing in DDD mode at 60 bpm;

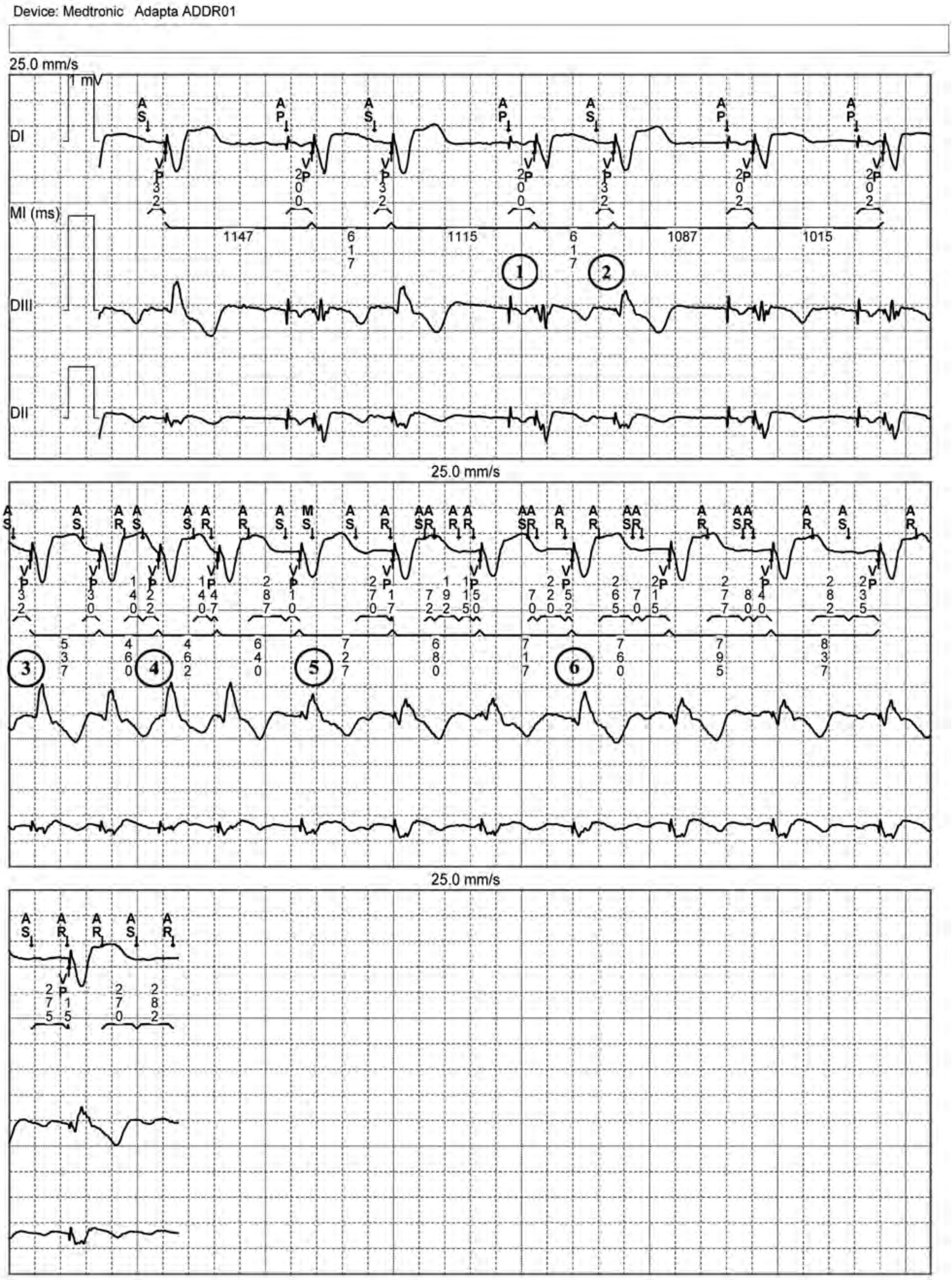
7: rhythm sensed in the atrium and paced in the ventricle (AS-VP);
8: frequent atrial extrasystoles sensed outside the refractory period and ventricular pacing (AS-VS);

Tracing 1c: change of programming to MVP mode at 70 bpm;

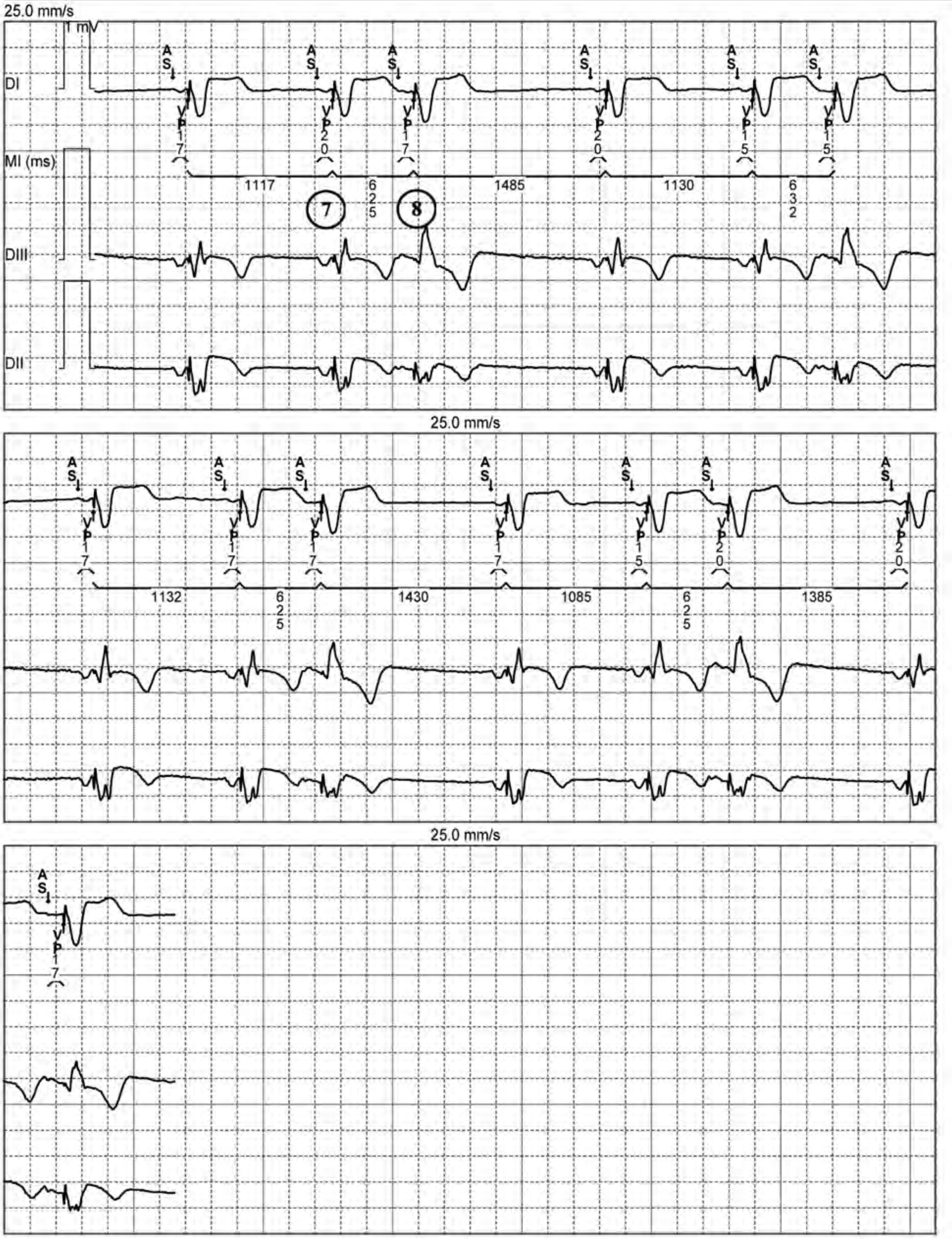
9: regular paced atrial and sensed ventricular rhythm AP-VS; elimination of the atrial extrasystoles;

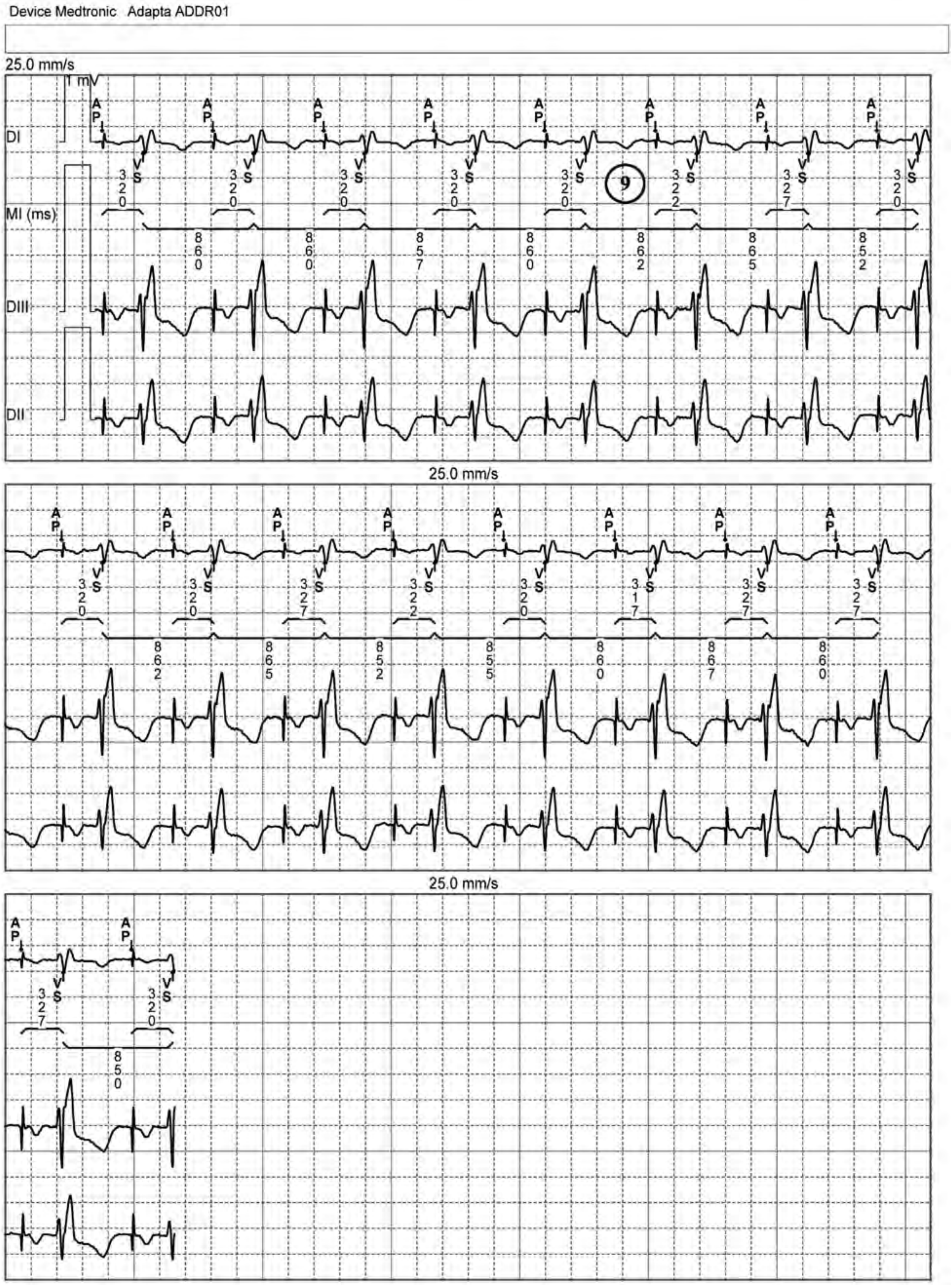
Comments

2 factors are determinant in the management of atrial arrhythmias in recipients of cardiac pacemakers: fallback must be systematically programmed to prevent rapid ventricular pacing during abnormal acceleration of the atrial rhythm; algorithms can be implemented to alleviate the arrhythmia burden. This tracing illustrates important points: 1) an Adapta pacemaker switches mode for episodes of atrial arrhythmias based on the following criteria: a) out of 7 consecutive intervals, 4 are shorter than the programmed rate detection interval (in this case 175 bpm); b) the efficacy of the various pacing algorithms in lowering the arrhythmia burden varies depending on the patient and remains to be confirmed in a large population. The tracings recorded in this patient are, nevertheless, promising. The episode of AF began with an atrial extrasystole, sensed with any pacing mode with a backup rate at 60 bpm. An increase in the backup rate to 70 bpm and the programming of the MVP mode completely suppressed the atrial extrasystoles. The suppression of the trigger, known to initiate episodes of atrial arrhythmias, might lower the arrhythmia burden and, in this patient, highlights the particular benefit of programming an algorithm that stabilizes the atrial rhythm, promotes atrial pacing, and eliminates the compensatory pauses occurring after atrial extrasystoles. The efficacy of this type of algorithm remains to be confirmed in a large population.


Device: Medtronic Adapta ADDR01
25.0 mm/s
1 mV
DI
MI (ms)
1147
1115
1087
1015
DIII
DII
25.0 mm/s
25.0 mm/s

Device: Medtronic Adapta ADDR01




Device Medtronic Adapta ADDR01
25.0 mm/s
1 mV
DI
MI (ms)
DIII
DII
AP
VS
9
320
860
857
862
865
852
327
322
317
855
867
850
25.0 mm/s
25.0 mm/s

Case 2: Absence of mode switch

Patient

This 74-year-old woman underwent implantation of an Adapta dual chamber pacemaker for syncopal episodes caused by complete AV block due to degenerative disease of the conduction system; she was seen in follow-up 3 months after device implantation for palpitation and signs of moderate left heart insufficiency.

EGM

Tracing 2a: the first channel is lead III of the surface ECG with the markers superimposed, the second is the ventricular EGM, and the third is lead II with the time intervals superimposed;

1: rapid and disorganized atrial rhythm, probably corresponding to AF; the atrial sensed (AS) events are tracked in the ventricle, causing a rapid, irregular, paced ventricular rhythm, at times reaching the maximal synchronous rate;

Tracing 2b: interrogation of the device revealed that mode switch was not programmed; tracings recorded before and after programming of mode switch;

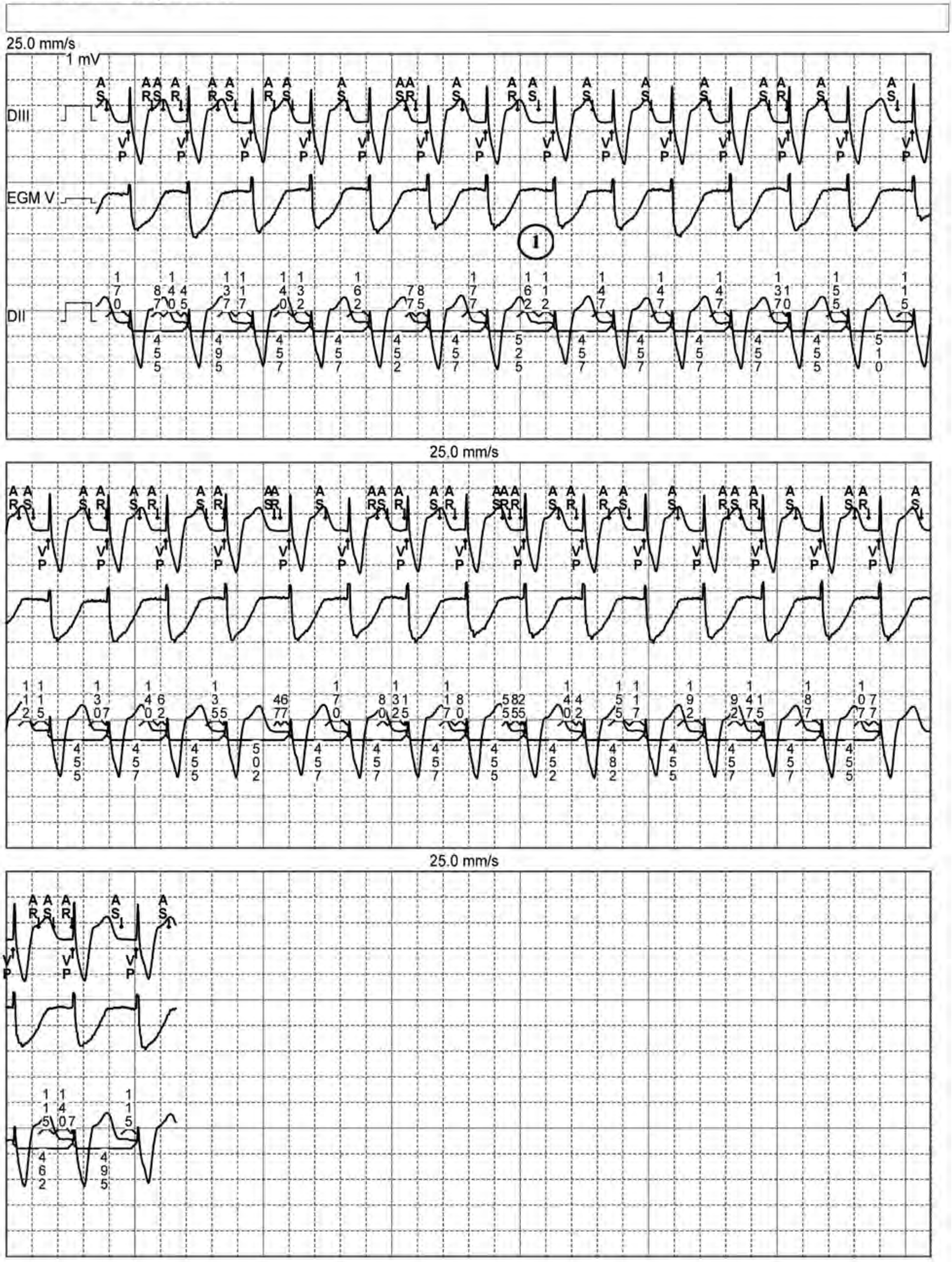
2: same as previous tracing;
3: programming of mode switch;
4: mode switch (MS);
5: slowing of the paced ventricular rate; a prolongation of the ventricular diastolic intervals enabled a better visualization of the detection of a rapid and disorganized atrial arrhythmia;

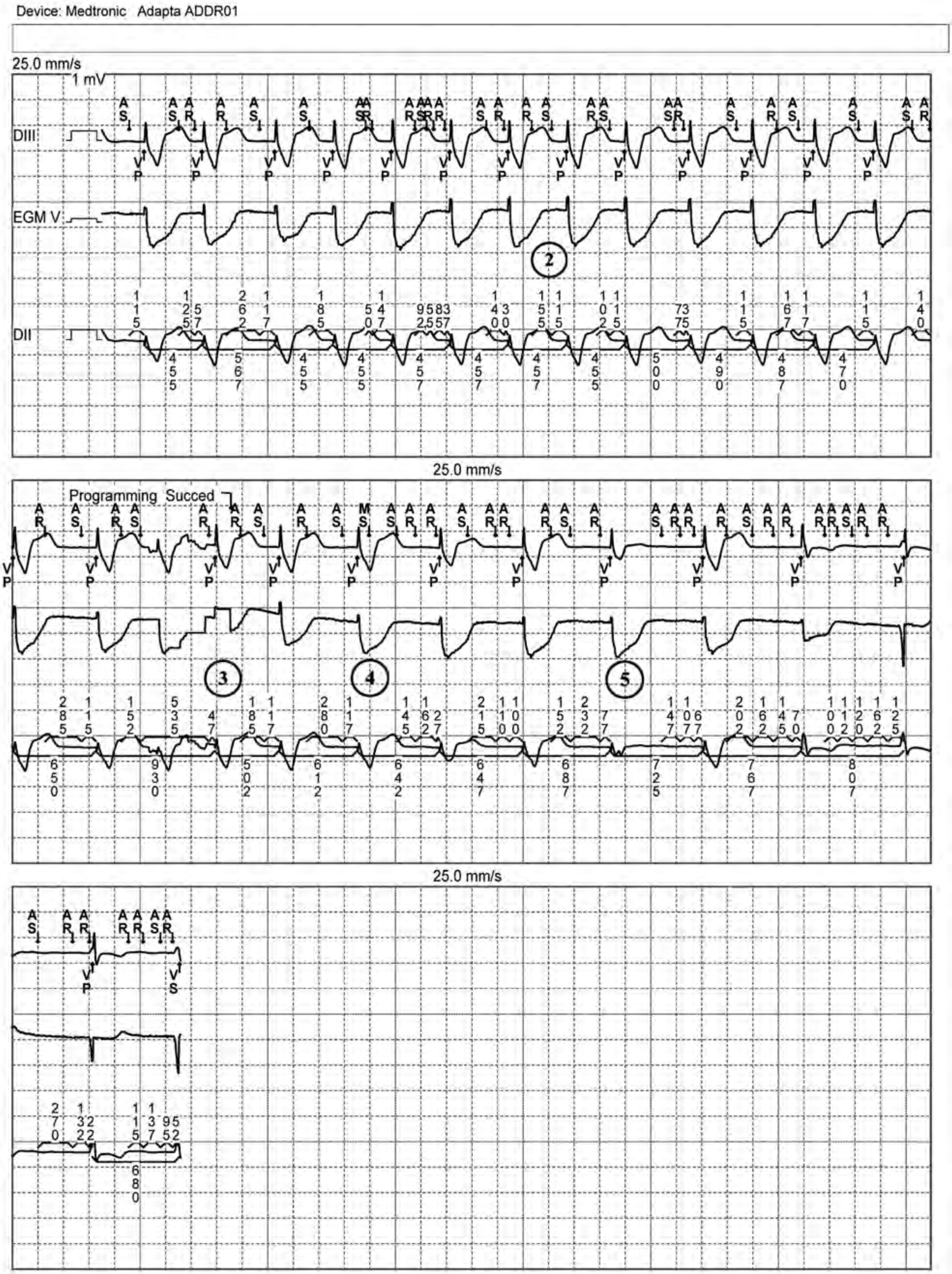
Comments

Mode switch is programmed as a nominal setting and should not be turned off, even in patients who have no history of atrial arrhythmia. In this patient in complete AV block, the absence of fallback was associated with prolonged, rapid ventricular pacing at the maximum tracking rate. A combined loss of atrial systole and runaway ventricular pacing was responsible for the manifestations of cardiac decompensation observed in this patient. Programming of mode switch restored a more physiologic heart rate. To prevent a sudden fall in ventricular rate, the return to the backup or the sensor-driven rate is progressive.

Along with the reprogramming of her pacemaker, the patient management included 1) the introduction of anticoagulation, 2) a conversation regarding the merits of converting her atrial arrhythmia. No rate slowing medication was needed for this patient who was in complete AV block. The recent onset of the arrhythmia and the absence of prominent dilatation of the atria on echocardiogram suggested that an attempt at pharmacologic or transthoracic DC shock cardioversion might be worthwhile.

Device: Medtronic Adapta ADDR01




Device: Medtronic Adapta ADDR01
25.0 mm/s
1 mV
DIII
EGM V
DII
25.0 mm/s
Programming Succed
25.0 mm/s

Case 3: AF and sensing failure

Patient

This 81-year-old man received an Adapta dual chamber pacemaker for atrial disease, sinus node dysfunction and episodes of paroxysmal AF; he was seen on routine visit.

EGM

Tracing 3a: the first channel is lead I of the surface ECG with the markers superimposed, the second channel shows the ventricular EGM, and the third is the marker channel;

1: rapid atrial rhythm with spontaneous AV conduction (AR-AS-VS);
2: period of atrial undersensing;
3: some of the atrial events falling outside the refractory period are followed by paced ventricular events (AS-VP);
4: improved atrial sensing and switch to DDIR mode (MS);
5: spontaneous ventricular events;

Tracing 3b: tracing recorded a few seconds later;

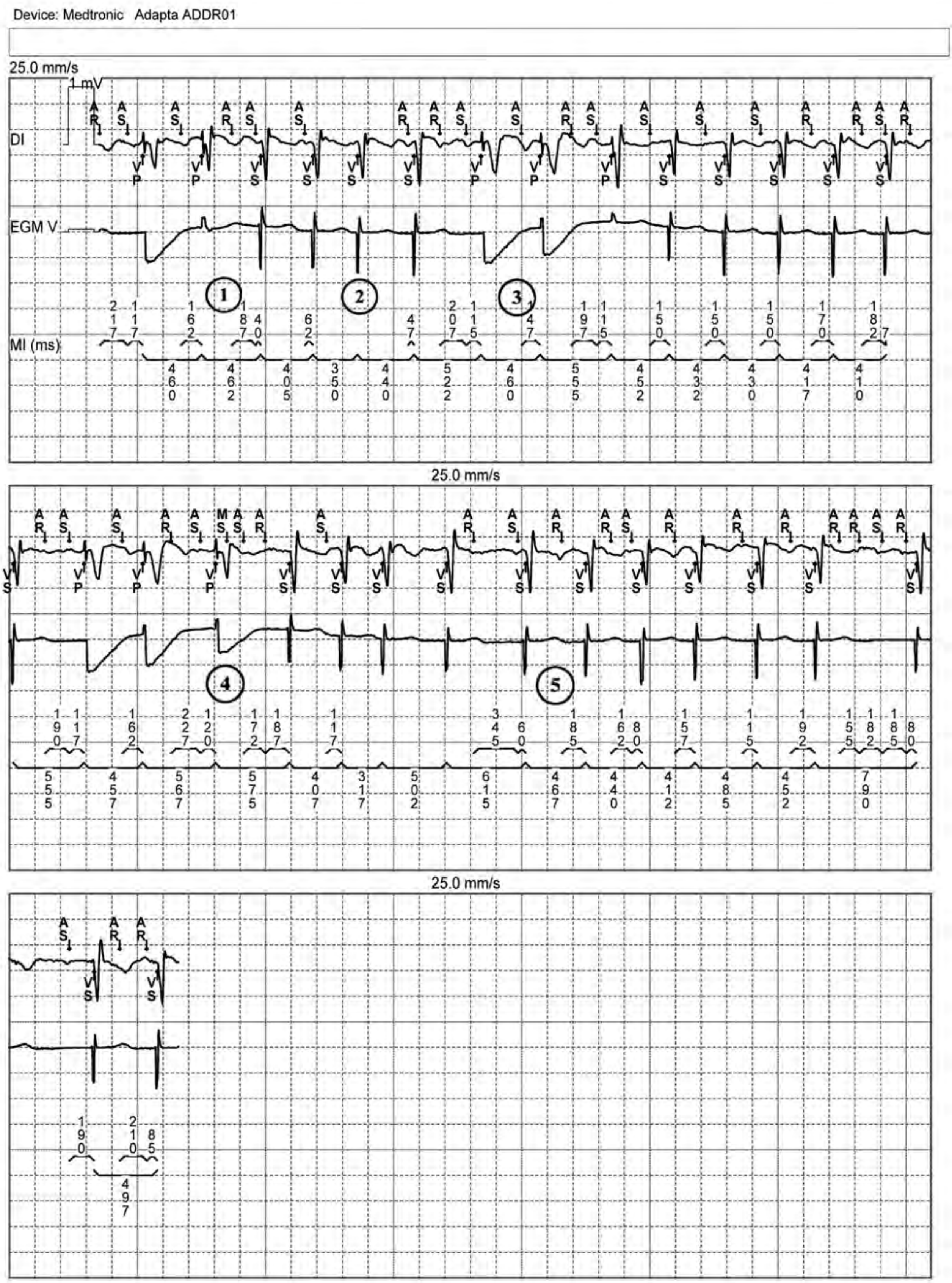
6: long series of atrial undersensing;
7: switch to DDD mode (MS);
8: return of paced ventricular event (VP) by exit from fallback mode (due to absence of sensed atrial signals);

Tracing 3c: no optimization of atrial sensing possible despite programming to the best capabilities of the device; change in pacing mode and programming to DDI;

9: persistence of atrial undersensing; absence of ventricular synchronization to the spontaneous atrial events;

Comments

The proper function of mode switch requires accurate sensing of arrhythmic atrial signals, the amplitude of which is most often lower than the amplitude of signals of sinus origin. Therefore, the proper sensing of atrial arrhythmias cannot be inferred by a measurement of the signals during sinus rhythm. In this patient, this intermittent sensing was responsible for repetitive alternation between synchronous (DDD) and fallback (DDIR) mode, with unnecessary ventricular pacing and energy consumption. Inhibition by the QRS alternated with ventricular pacing synchronized to atrial sensing, which was programmed to the highest value allowed by the device, leaving no room for additional optimisation. Programming of the DDI mode seemed appropriate for this patient presenting with atrial disease, as it enabled atrial pacing when he was in sinus rhythm, and prevented the development of erratic ventricular pacing due to the absence of mode switch when he was in AF.
In contrast to the previous tracing, a rate slowing treatment was necessary for this patient whose AV conduction was preserved. A treatment with a beta-adrenergic blocker or a calcium antagonist was preferred as it was likely to be effective at rest as well as during exercise. These treatments are also likely to slow the sinus rate and promote atrial pacing and AV synchronization in DDI mode.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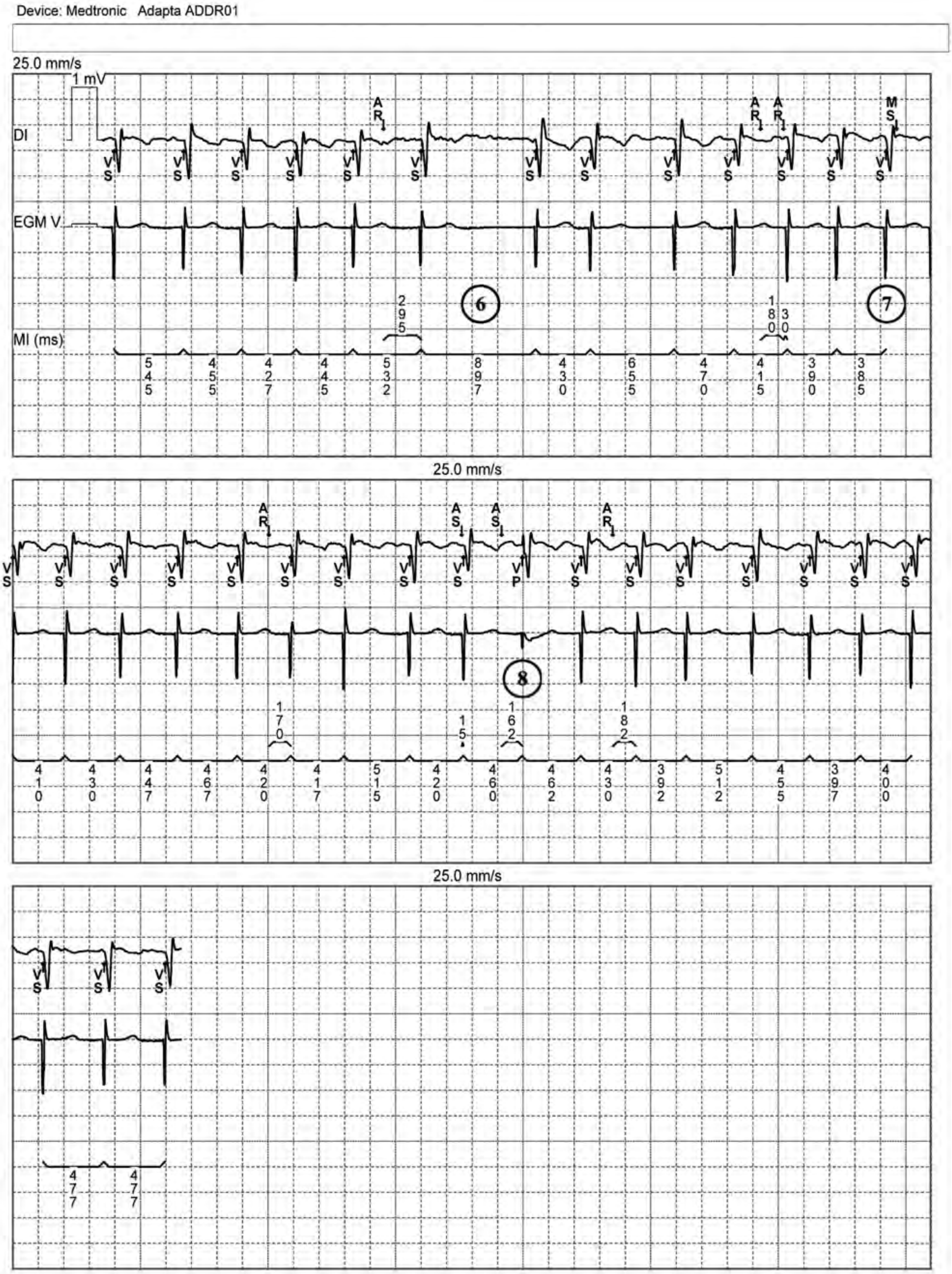
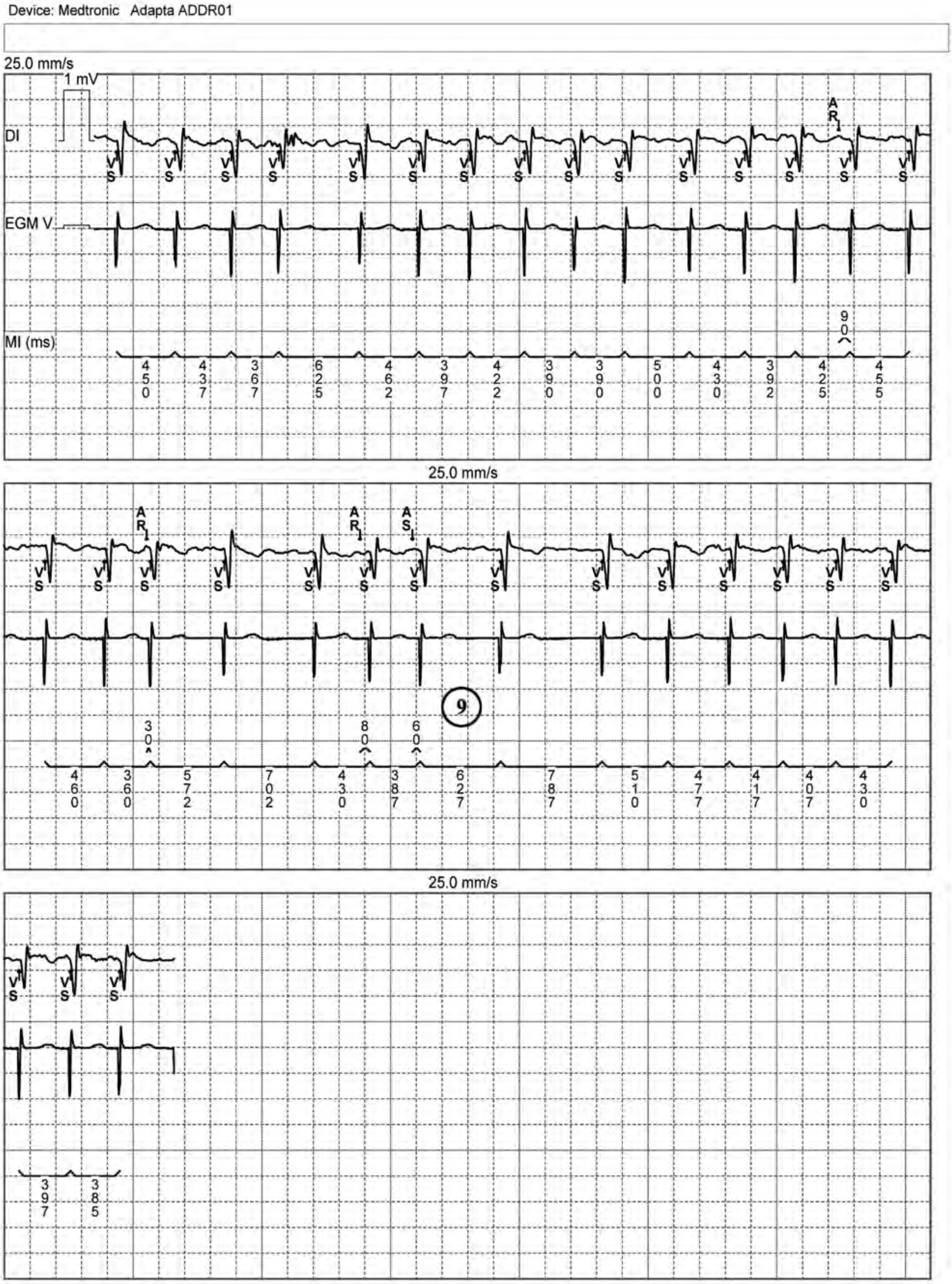
25.0 mm/s
1 mV
DI
EGM V
MI (ms)
25.0 mm/s
25.0 mm/s


Device: Medtronic Adapta ADDR01
25.0 mm/s
1 mV
DI
EGM V
MI (ms)
6
7
25.0 mm/s
8
25.0 mm/s


Device: Medtronic Adapta ADDR01
25.0 mm/s
1 mV
DI
EGM V
MI (ms)
450 437 367 625 462 397 422 390 390 500 430 392 425 90 455
25.0 mm/s
460 360 30 572 702 430 80 387 60 627 787 510 477 417 407 430
9
25.0 mm/s
397 385

Case 4: Sensing optimization and diagnosis of AF

Patient

This 77-year-old male recipient of Adapta dual chamber pacemaker implanted for complete AV block was seen for a routine evaluation.

EGM

Tracing 4a: the first channel is lead II of the surface ECG with the markers superimposed, the second shows the atrial EGM and the last channel is lead I with the time intervals superimposed;

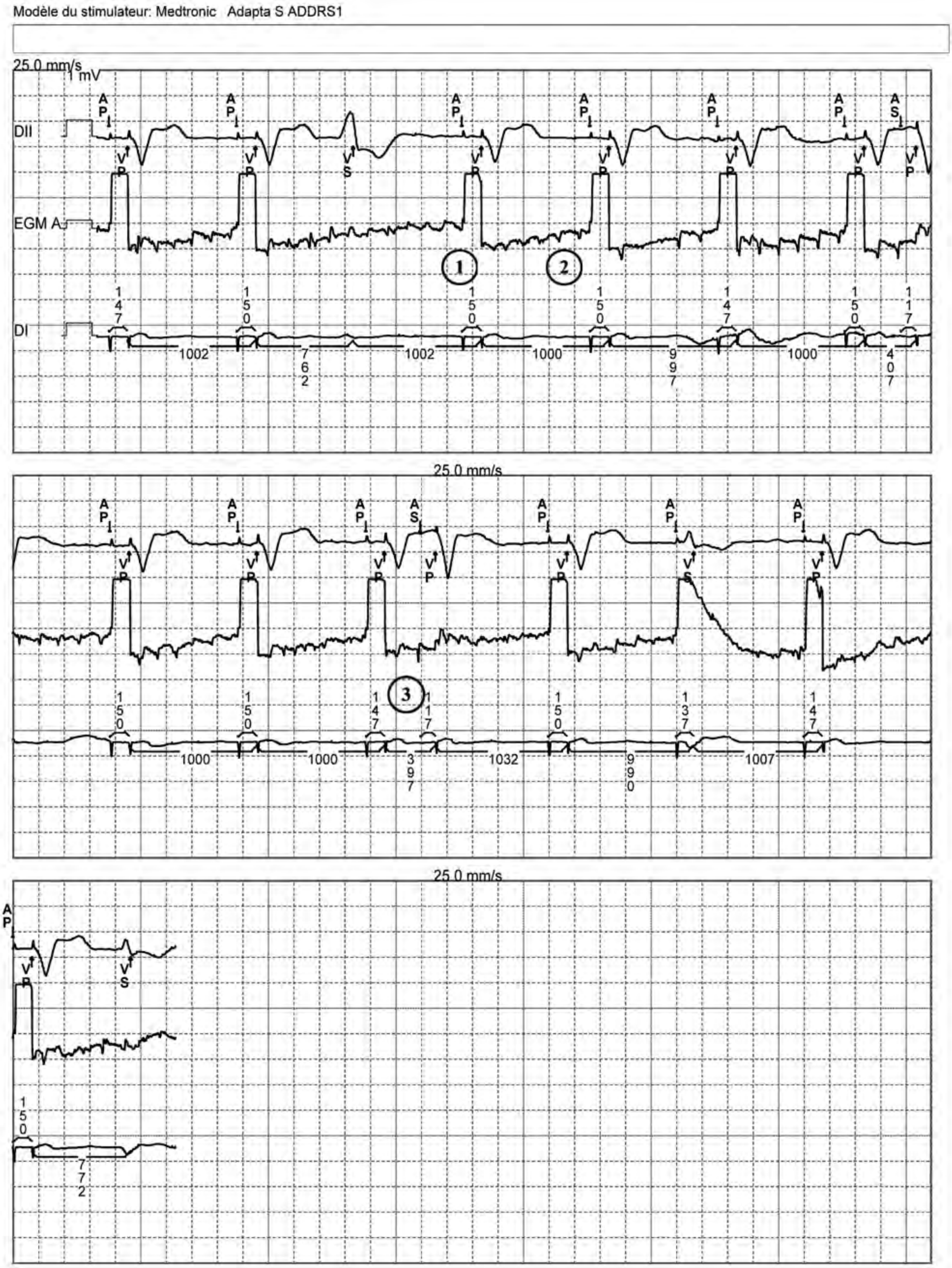
1: atrial and ventricular pacing (AP-VP);
2: the atrial EGM channel shows low-amplitude atrial signals that are not sensed by the device, explaining the presence of atrial pacing (AP);
3: one of the slightly higher-amplitude EGM is sensed and followed by an AV delay and ventricular pacing;

Tracing 4b: atrial sensing is initially programmed at 0.5 mV; optimization to the highest sensitivity of the device;

4: same as previous tracing;
5: change in the programming of atrial sensing;
6: improved atrial sensing and mode switch (MS);
7: gradual slowing of ventricular pacing;

Comments

Runaway ventricular pacing observed during rapid atrial rhythm can only occur when the atrial EGMs are sensed. In presence of an atrial arrhythmia that is consistently poorly sensed and associated with complete AV block, the pacing mode is DVI-like, with AV pacing at the backup rate or at the on-going sensor-driven rate. Atrial pacing is unnecessary and wastes energy. Furthermore, the device cannot memorize the episode, which, consequently, might be missed if the patient is asymptomatic. When the atrial signals are intermittently sensed, the ventricular rhythm becomes erratic.
In this patient, an increase in atrial sensitivity enables a precise diagnosis of the arrhythmia with switch of DDD toward DDIR mode. In Medtronic pacemakers, rate responsiveness is systematically programmed during mode switch, including when the initial mode is not sensor-driven. This seems appropriate for this patient who is in complete AV block and incapable of chronotropic adaptation during AF.


Modèle du stimulateur: Medtronic Adapta S ADDRS1
25.0 mm/s 1 mV
DII
EGM A
DI
AP VP AS VS
1
2
3
1002
762
1000
997
407
1032
990
1007
772
25.0 mm/s
25.0 mm/s


Device: Medtronic Adapta S ADDRS1
25.0 mm/s
Successful Programming
DII
EGM A
DI
4
5
6
7
25.0 mm/s
25.0 mm/s

Case 5: Blanked flutter

Patient

This 57-year-old woman presented with pulmonary arterial hypertension, on a treatment of anticoagulation and amiodarone for episodes of paroxysmal AF, underwent implantation of a dual chamber pacemaker for management of syncopal episodes due to paroxysmal AV conduction disorder; she was hospitalized for cardiac decompensation with palpitations for 2 weeks.

EGM

Tracing 5a: the first channel is lead I of the surface ECG with the markers superimposed, the second shows the atrial EGM and the third shows the ventricular EGM;

1: rapid atrial rhythm at approximately 130 bpm (upper synchronous rate programmed at 140 bpm) followed by 1:1 ventricular pacing; the atrial EGM reveals that the rhythm is atrial tachycardia with every other event not sensed by the device, as they fell in the post-ventricular atrial blanking period;

Tracing 5b: interrogation of the pacemaker indicated that the blanked flutter search algorithm was not programmed 'on'; the algorithm was then turned ON;

2: continuation of the rapid AS-VP rhythm;

3: successful programming of the blanked flutter search algorithm;

4: over 8 consecutive cycles, the AA interval is shorter than twice the sum of the AV delay + atrial post-ventricular blanking period, and shorter than twice the programmed rate sensing interval: suspicion of 2:1 flutter; at the 9th cycle, the PVARP is lengthened; the event previously labeled AS is now labeled AR and no longer followed by ventricular pacing; the following atrial event, thus far concealed in the post-ventricular pacing atrial blanking period, is visualized in absence of ventricular pacing and labeled AS; diagnosis of blanked 2:1 flutter;

5: switch (MS) to mode DDIR;

6: gradual slowing of the ventricular pacing rate;

7: return of the spontaneous ventricular rhythm;

Tracing 5c: the 12-lead ECG is consistent with typical flutter;

8: the tracing shows persistent atrial flutter with variable AV conduction;

Tracing 5d: the patient undergoes successful anticoagulation; an attempt is made at conversion of the atrial arrhythmia with rapid atrial pacing, using the pacemaker;

9: burst of rapid atrial pacing; the 2 - 3 sec duration and the rate (slightly faster than the flutter) of pacing were chosen by the cardiologist;

10: unsuccessful burst and persistence of atrial flutter;

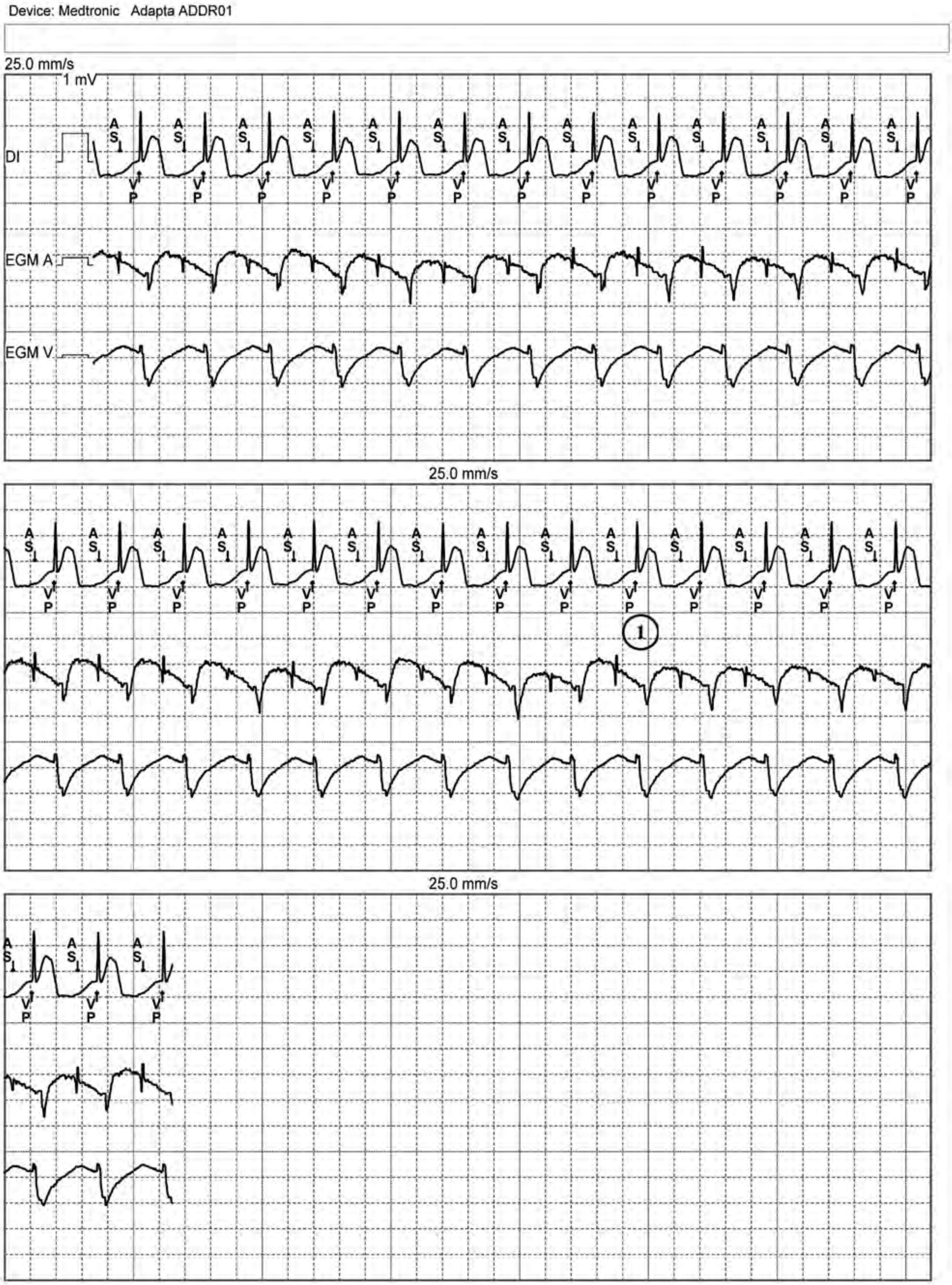
Tracing 5e: new conversion attempt;

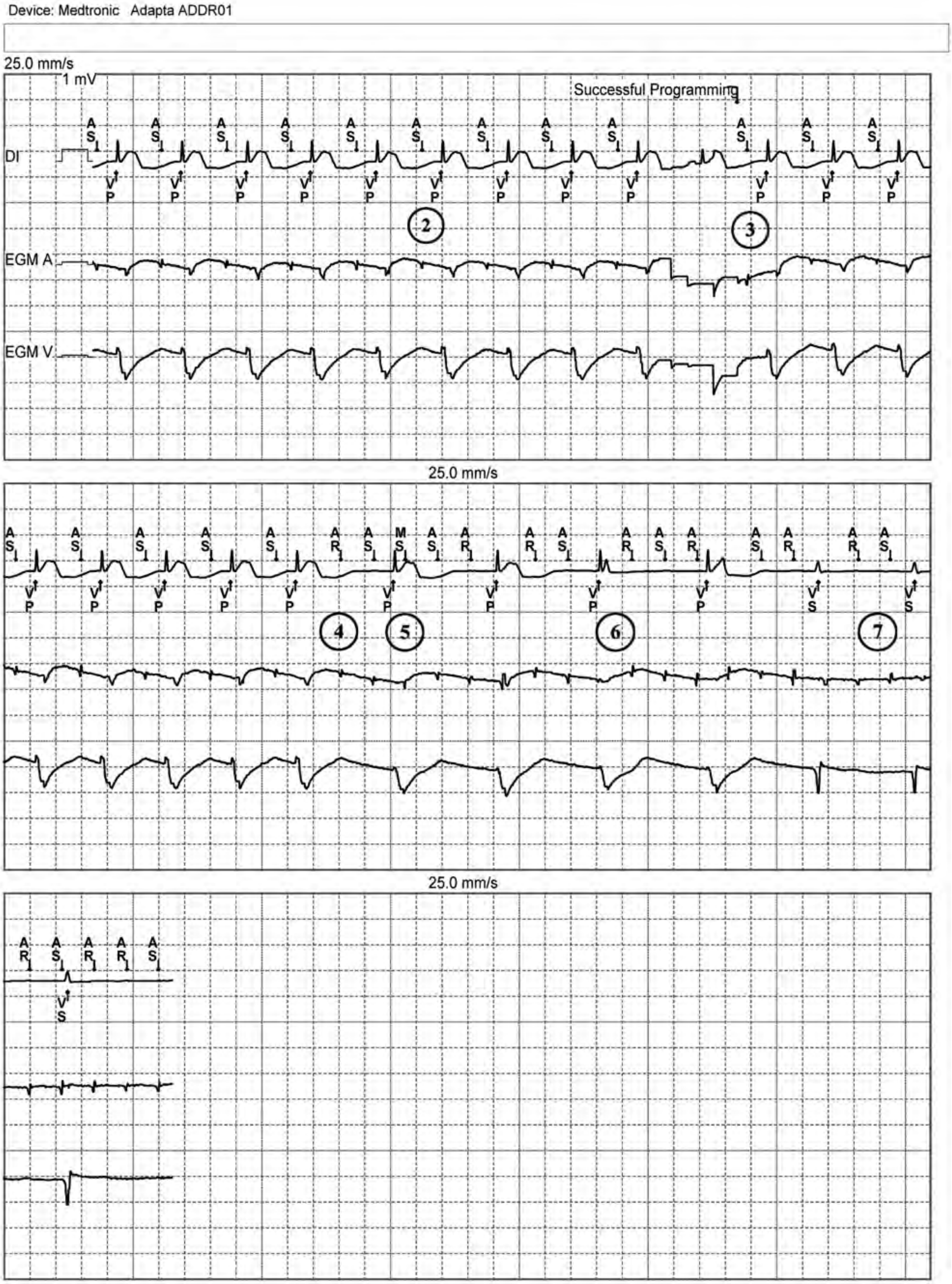
11: another burst, faster than the previous attempt;

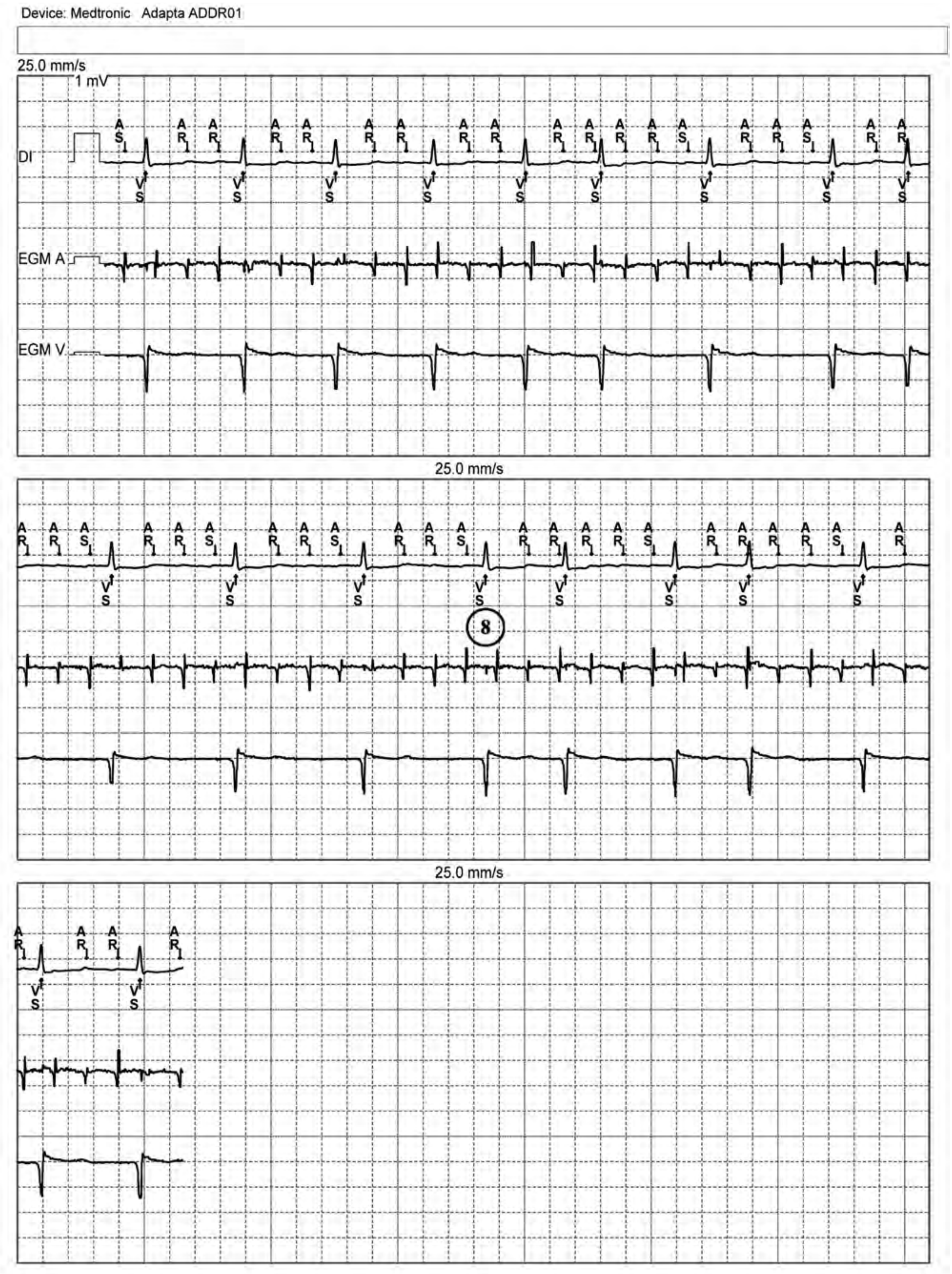
12: conversion of atrial flutter to AF; the atrial EGM are faster and irregular in rate and morphology;

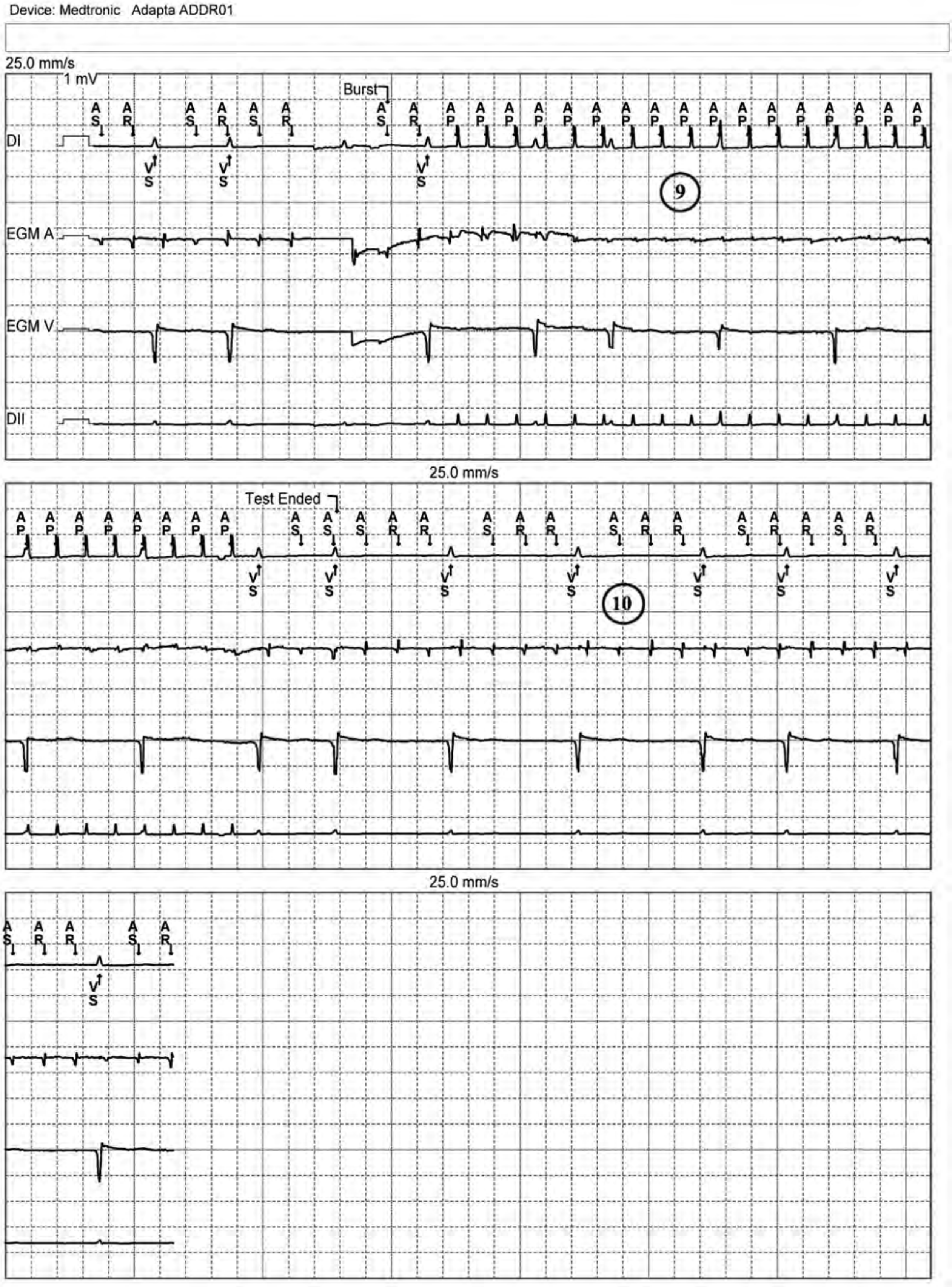
Comments

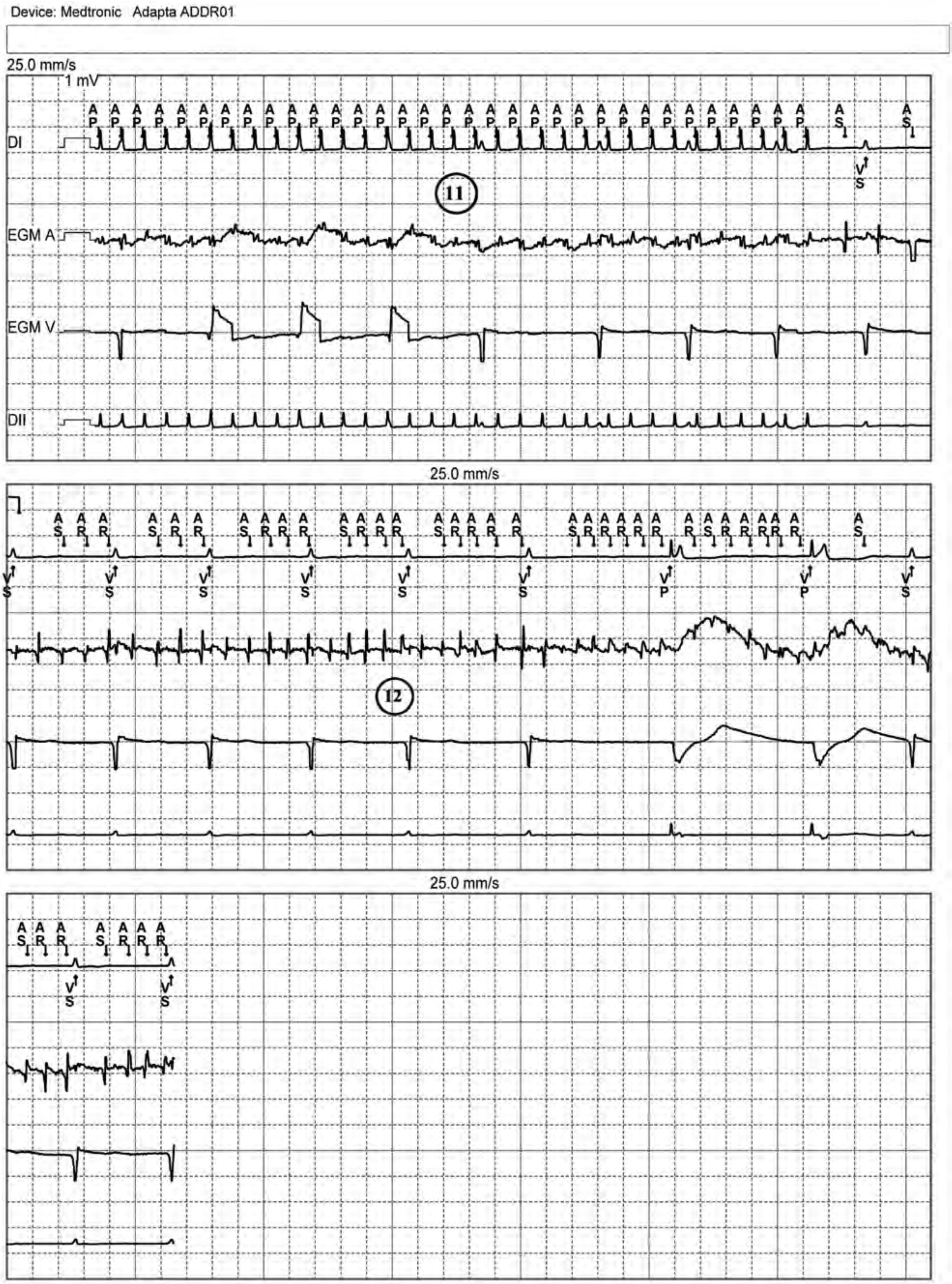
In this patient, the initial absence of fallback for this undiagnosed episode of flutter was the cause of prolonged, rapid ventricular pacing, which promoted the development of cardiac decompensation. She complained of palpitations of 2-week duration, day and night. The programming of the blanked flutter search algorithm interrupted this inappropriate pacing and returned ventricular conduction to a more acceptable rate. The attempt at conversion of the arrhythmia could be made only after effective anticoagulation had been achieved (>2 INR for >3 weeks). Pacing at a rate faster than the flutter was ineffective and further acceleration of pacing transformed flutter to AF. This patient returned spontaneously to sinus rhythm a few minutes after the cessation of pacing. Atrial flutter often persists for prolonged periods of time. An attempt at conversion might be immediately successful and restore sinus rhythm, or the success might be delayed after an initial transformation of flutter to AF.


Device: Medtronic Adapta ADDR01
25.0 mm/s
1 mV
DI
EGM A
EGM V
AS
VP
25.0 mm/s
1
25.0 mm/s


Device: Medtronic Adapta ADDR01
25.0 mm/s
1 mV
Successful Programming
DI
EGM A
EGM V
2
3
25.0 mm/s
4
5
6
7
25.0 mm/s


Device: Medtronic Adapta ADDR01
25.0 mm/s
1 mV
DI
EGM A
EGM V
25.0 mm/s
8
25.0 mm/s


Device: Medtronic Adapta ADDR01
25.0 mm/s
1 mV
Burst
DI
EGM A
EGM V
DII
9
25.0 mm/s
Test Ended
10
25.0 mm/s


Device: Medtronic Adapta ADDR01
25.0 mm/s
1 mV
DI
EGM A
EGM V
DII
11
25.0 mm/s
12
25.0 mm/s

Case 6: Function of the "conducted AF response" algorithm

Patient

This 64-year-old man underwent implantation of an Adapta dual chamber pacemaker; he suffered from paroxysmal episodes of AF with rapid ventricular response accurately diagnosed by the device; upon arrival for a routine follow-up visit, the pacemaker is in DDIR fallback mode with a rapid spontaneous ventricular rhythm; the device was programmed during the visit to the conducted AF response algorithm and the tracing was recorded.

EGM

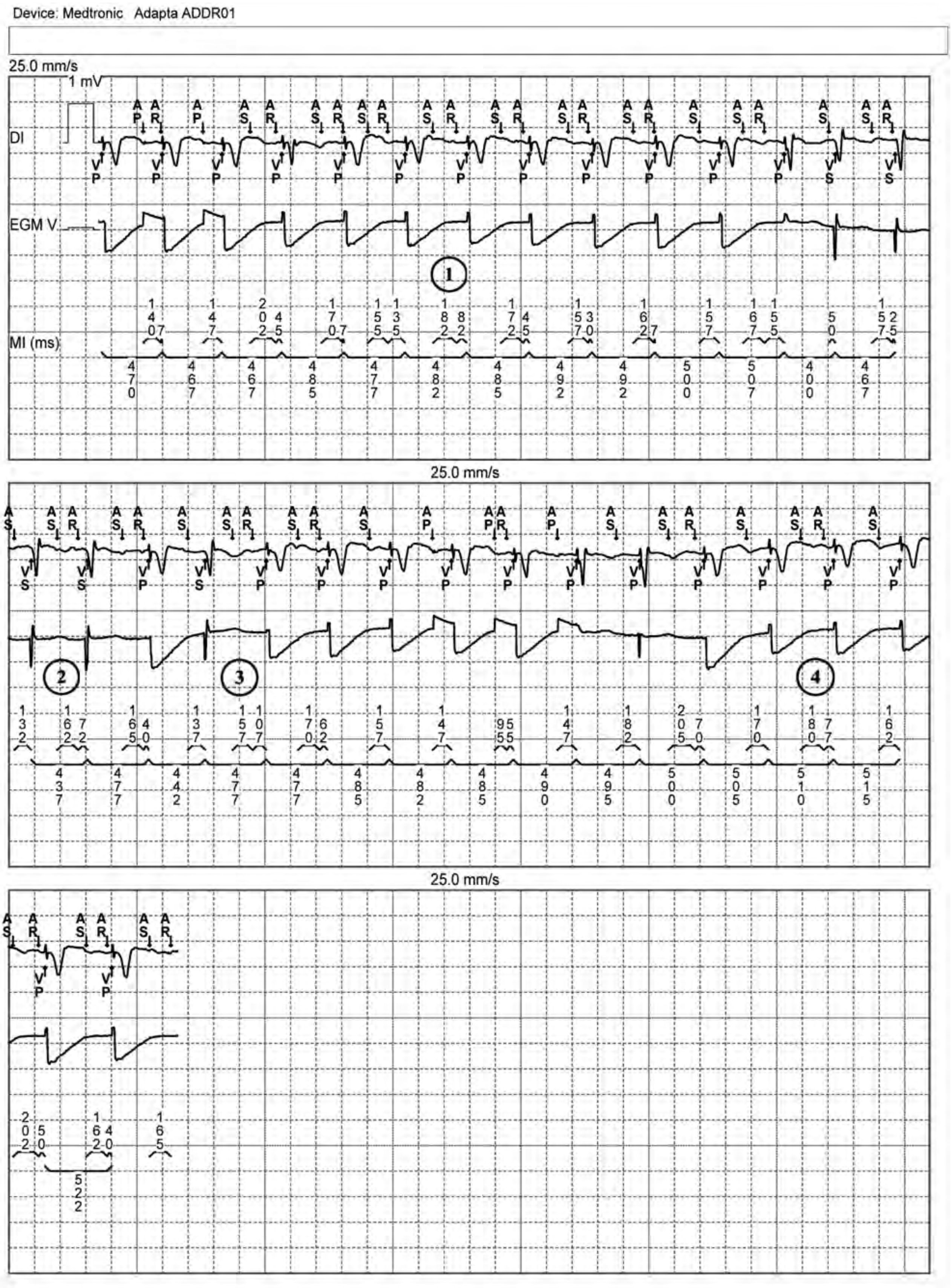
The first channel is lead I of the surface ECG with the event markers superimposed, the second shows the atrial EGM and the third channel shows the time intervals;

1: AF accurately diagnosed by the pacemaker; the device is in fallback mode; the ventricles are paced at a decreasing rate;
2: emergence of rapid, spontaneous ventricular events at a rate above the on-going ventricular pacing;
3: return of ventricular pacing at a rate faster than before, prompted by the rapid VS cycles due to the function of the response to conducted AF algorithm;
4: decrease in the ventricular pacing rate in regular stages;

Comments

In patients presenting with AF and rapid AV conduction, the rhythm irregularity may be the cause of disabling symptoms and a fall in cardiac output. The principal aim of the response to conducted AF algorithm is to eliminate long diastolic intervals. The algorithm operates only during mode switches. The increase in pacing rate caused by the response to conducted AF algorithm is limited by the programmed upper rate. Rapid ventricular pacing might also decrease the spontaneous mean ventricular rate by the phenomenon of concealed retrograde conduction.

This type of algorithm has some limitations. Its ability to control symptoms in a large population seems uncertain. In addition, this forced pacing is energy consuming.


Device: Medtronic Adapta ADDR01
25.0 mm/s
1 mV
DI
EGM V
MI (ms)
1
2
3
4
25.0 mm/s
25.0 mm/s

Case 7: AF burden and recording on AN AF episode

Patient

This 57-year-old man received an Ensura dual chamber pacemaker for management of complete AV block; he had a history of paroxysmal AF treated with amiodarone and was seen for routine follow-up.

EGM

Tracing 7a: initial interrogation and AT/AF summary;

1: this summary provides general information regarding the AF burden and compares with previous interrogations; it offers details regarding the percentage of time spent in arrhythmia, the mean duration of AF and the number of daily arrhythmic episodes;

Tracing 7b: analysis of the episodes of atrial arrhythmia;

2: this episode lasted >2 hours with a rapid atrial rate, fallback and pacing at the resting rate;

Tracing 7c: graphic representation of the episode;

3: sinus rhythm with 1:1 AV association;

4: onset of atrial arrhythmia with AV dissociation and ventricular paced rhythm in fallback;

Tracing 7d: EGM corresponding to this episode;

5: atrial arrhythmia accurately detected by the pacemaker and ventricular pacing;

Comments

The interrogation of the pacemaker memory is an indispensable step of routine interrogations. It enables the detection of symptomatic or asymptomatic arrhythmic episodes, and ascertains their rate, number and evolution as a function of the various treatments attempted, and their impact on ventricular conduction. The ability of viewing the graphs and EGMs pertaining to these episodes allows a verification of the diagnosis made by the pacemaker and the elimination of false positive diagnoses, such as those due to far-field sensing.

AT/AF Summary

Device: **Ensura DR MRI EN1DR01**

	Prior. session 15-Nov-2011 to 12-Dec-2011 27 days		**Last. session** 12-Dec-2011 to 15-May-2012 5 months	
AT/AT Summary				
% of time AT/AF	0.4	%	1.2	% ↑
Average AT/AF time/day	0.1	hours/day	0.3	hours/day ↑
Monitored AT/AF Episodes	1.2	per day	0.7	per day ↓
% of time Atrial Pacing	36.3	%	37.9	% ↑
% of time atriale	0.0	%	0.0	%A
AT-NS (>6 beats)	1.0	per day	0.3	per day ↓

(1)

Pp

Monitored AT/AF Episode # 378

Device : **Ensura DR MRI EN1DR01**

Episode #378: 11-May-2012 02:09:15

Episode Summary

Initial Type	AT/AF Monitor (spontaneous)
Duration	2.7 h
AV Max Rate	600 min-¹/VP
A. Median	353 min-¹ (170 ms)
Activity at onset	Off, Sensor = 65 bpm

(2)

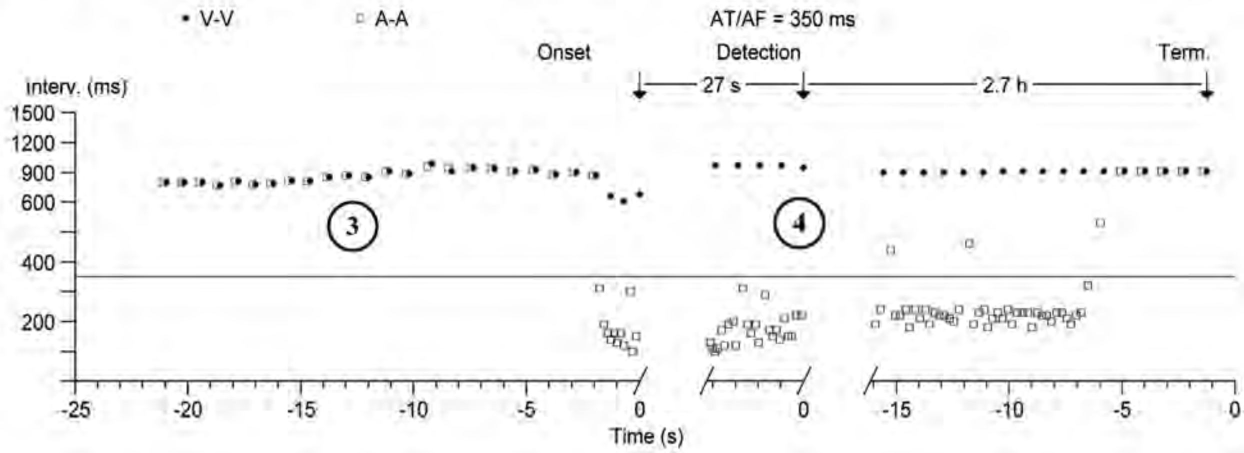
Parameter Settings		Zones		A interval (rate)
AT/AF	Monitor	1	AT/AF	350 ms (171 min-¹)

EGM	Source	Range	Sensitivity	
EGM1	A tip to A ring	+/- 8 mV	Atrial	0.3 mV
EGM2	RV tip to RV ring	+/- 8 mV	RV	0.9 mV

Monitored AT/AF Episode # 378

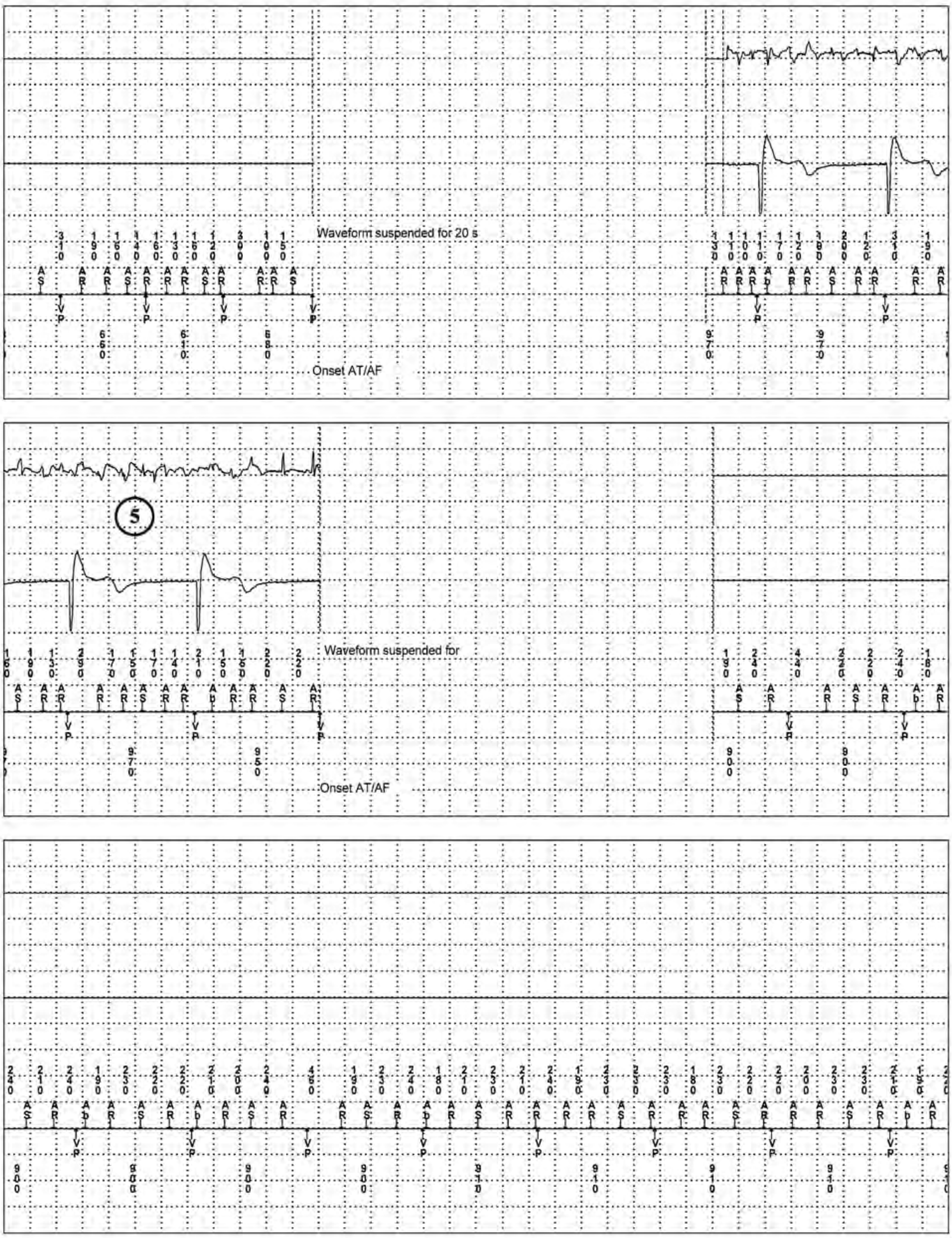
Device: **Ensura DR MRI EN1DR01**

Type	Nº ID	Date	Time hh:mm	Duration hh:mm:ss	Avg Bpm A/V	Max bpm A/V	Activity at Onset
AT/AF	378	11-May-20..	02:09	02:40:36	349/61	600/VP	Rest



Monitored AT/AF Episode #378

Device: **Ensura DR MRI EN1DR01**



Case 8: Episode of ventricular tachycardia recorded in memory

Patient

This 74-year-old man presenting with ischemic cardiomyopathy, a left ventricular ejection fraction at 45%, and syncope without prodrome, underwent implantation of an Ensura dual chamber pacemaker in the background of a prolonged PR interval and diurnal episodes of Wenckebach rhythm; an episode of ventricular tachycardia was recorded in the device memory.

EGM

Tracing 8a: graph illustrating the episode;

1: AV synchronization;
2: episode of ventricular tachycardia with AV dissociation;
3: spontaneous return of sinus rhythm; alternation of short-long ventricular cycles;

Tracing 8b: EGM corresponding to this episode;

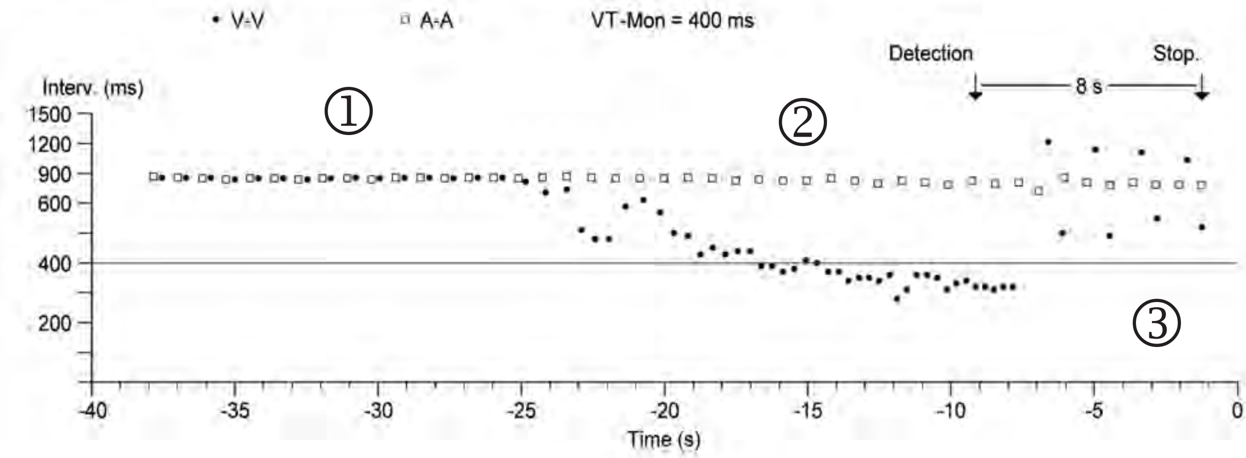
4: episode of ventricular tachycardia with AV dissociation;
5: spontaneous termination; alternation of short-long ventricular cycles consistent with ventricular bigeminy;

Comments

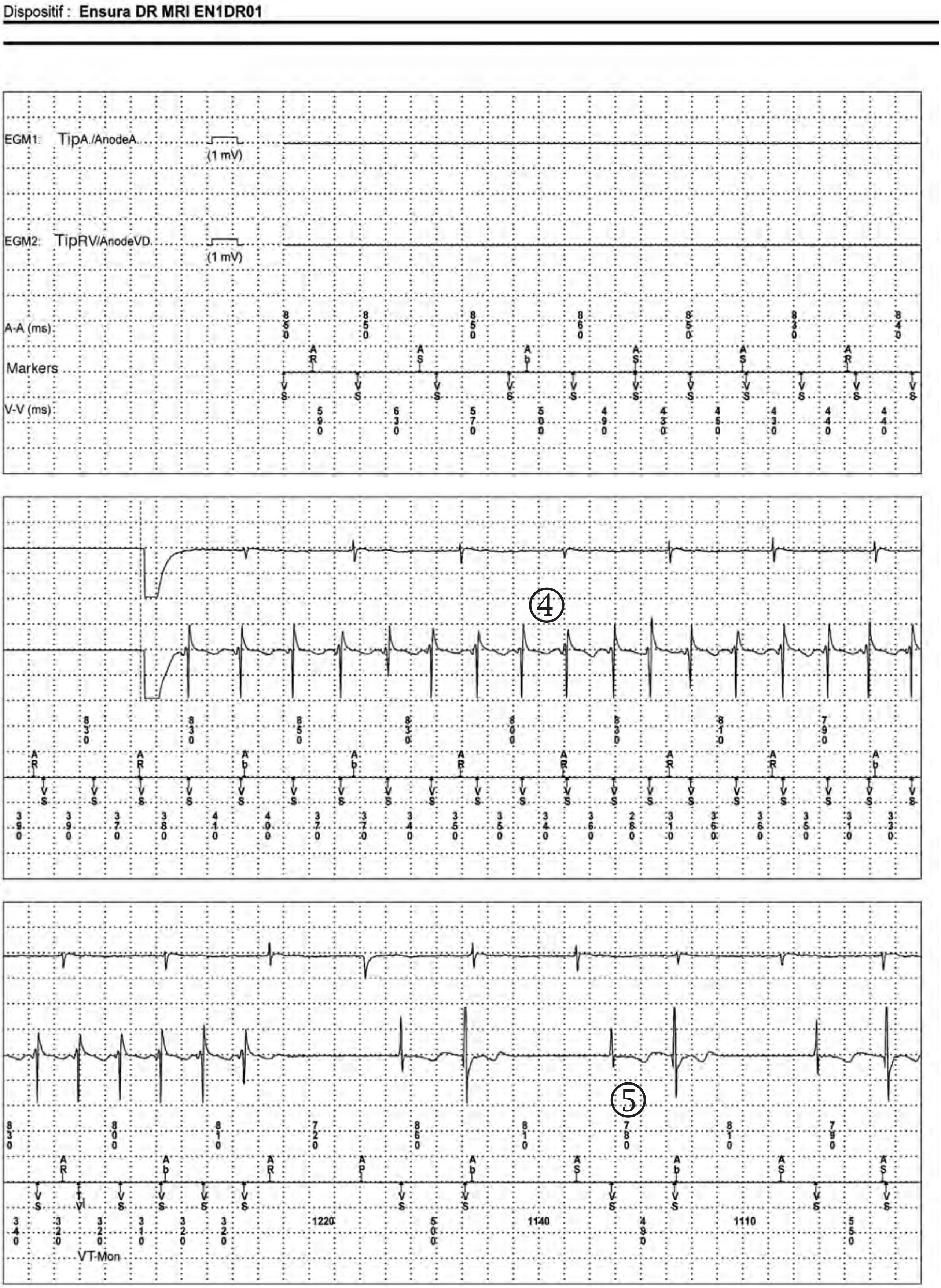
This tracing highlights the challenging issue of recordings of runs of non-sustained ventricular tachycardia in pacemaker recipients. The recorded episode might call into question the initial diagnosis. The patient underwent pacemaker implantation after a syncopal episode occurring in the background of AV conduction abnormalities. The device memory revealed another potential diagnosis, i.e. rapid ventricular tachycardia in the context of ischemic cardiomyopathy. It seems legitimate, in this patient, to proceed with programmed ventricular stimulation, and to upgrade his system to an implantable cardioverter defibrillator, if sustained ventricular tachycardia is inducible.

Device: **Ensura DR MRI EN1DR01**

Type	Nº ID	Date	Time hh:mm	Duration hh:mm:ss	Avg Bpm A/V	Max bpm A/V	Activity at Onset
VT-Mon	4	29-Fev-2012	14:46	:08	75/94	---/188	Rest



9995 Version logiciel 7.3


Dispositif : Ensura DR MRI EN1DR01
EGM1: TipA./AnodeA.
(1 mV)
EGM2: TipRV/AnodeVD
(1 mV)
A-A (ms)
Markers
V-V (ms)
④
⑤
VT-Mon

Case 9: Noise sensing

Patient

A 63-year-old man underwent implantation of an Adapta dual chamber pacemaker for management of syncopal events due to paroxysmal AV block; at a routine device interrogation, an episode of rapid ventricular rate was stored in the device memory.

EGM

Tracing 9a: graph and episode data:

1: episode of rapid ventricular rhythm with AV dissociation lasting 5 sec (maximal atrial rate = 84 bpm, maximal ventricular rate = 334 bpm);
2: normal rhythm;
3: sudden acceleration of the ventricular rhythm;

Tracing 9b: tracing coinciding with the episode:

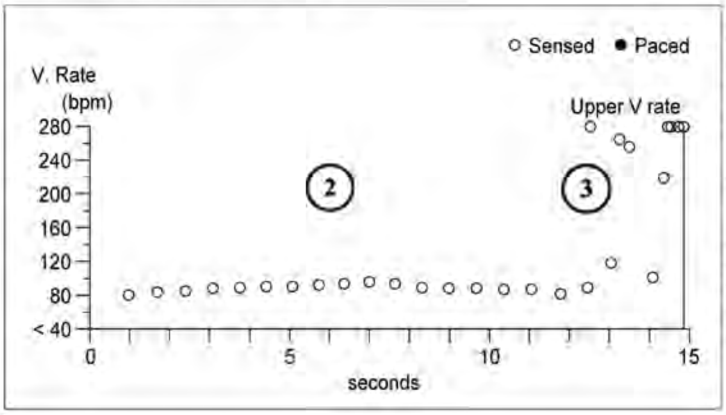
4: sinus rhythm conducted to the ventricles;
5: ventricular oversensing of noise;
6: end of noise oversensing;

Comments

This tracing illustrates the recording of a 50 Hz source of noise by the pacemaker instead of a ventricular rhythm disorder, which can be ascertained by examination of the ventricular EGM; the event markers and intervals are also highly suggestive, particularly the very short, non-physiologic ventricular cycles.
It is, therefore, mandatory to verify systematically all episodes stored in memory. An erroneous diagnosis made by the device might be rectified by analysing the EGM. This patient was not pacemaker-dependent and the sensing of noise was not associated with bradycardia. Older pacemakers were considerably more subject to this type of interference, as they operated in unipolar configurations. In these circumstances, triggered modes were used to prevent all pauses.

Device: Medtronic Adapta ADDR03

Zoom - Onset Collected - 04.12.11 21:21



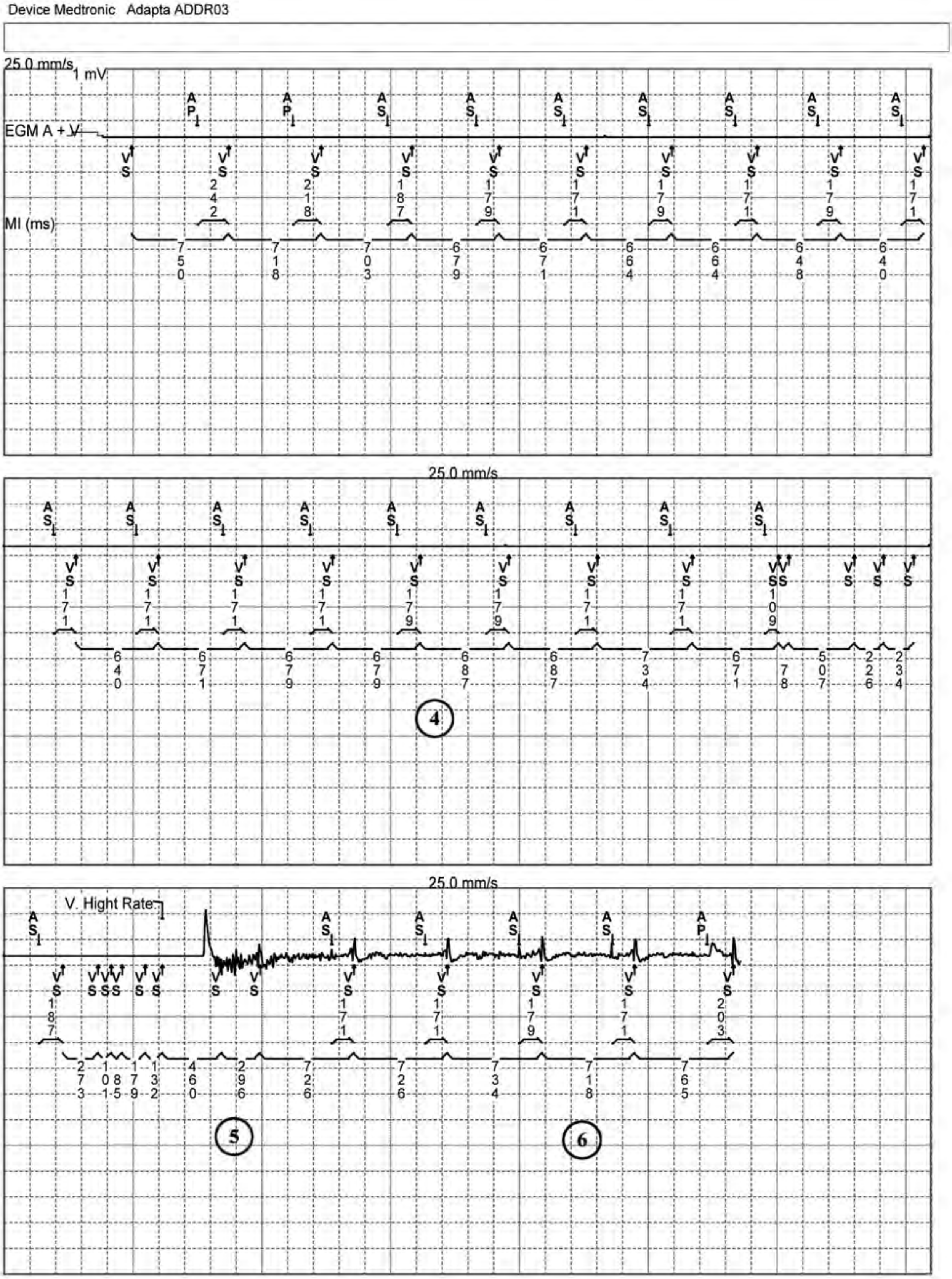
Initial Interrogation

Mode	AAIR<=>DDDR
Lower Rate	60 bpm
Upper Tracking Rate	130 bpm
Upper Sensor Rate	130 bpm
Detection Rate	180 bpm
Detection duration	5 cycles

Episodes Data

Duration (hh:mm:ss)	00:00:05
Max A rate	84 bpm
Max V rate	334 bpm

1


Device Medtronic Adapta ADDR03
25.0 mm/s
1 mV
EGM A + V
MI (ms)
25.0 mm/s
4
25.0 mm/s
V. Hight Rate
5
6