We present a case of a single chamber atrial pacemaker implanted for sinus node dysfunction and treatment of macroreentrant atrial tachycardias with atrial anti-tachycardia pacing. The patient presented with sustained atrial tachycardia above the detection rate, however, the device was unable to detect the tachycardia and did not deliver the programmed therapy. We discuss the nuances of the atrial tachyarrhythmia detection algorithms, and the programming strategies to maximize detection of atrial arrhythmias in a single chamber atrial pacemaker.
these as the ventricular events for its algorithms. The ventricular pacing is ineffective because there is no ventricular lead; therefore, the ventricular pacing output is programmed at minimum amplitude and pulse width. Programmed parameters are as follows:

| Pacing mode                              | DDDR |
|------------------------------------------|------|
| Lower rate limit (LRL)                  | 75 bpm (800 ms) |
| Maximum tracking rate (MTR)             | 110 bpm (545 ms) |
| Maximum sensor indicated rate (SIR)     | 110 bpm (545 ms) |
| Post-ventricular atrial refractory period (PVARP) | 310 ms |
| Paced AV delay                          | (180 ms) |
| Sensed AV delay                         | (150 ms) |
| Atrial tachycardia/fibrillation (AT/AF) detection | Rate 111 bpm (541 ms) |
|                                          | Detection interval 60 s |
|                                          | Atrial tachycardia therapy Antitachycardia pacing (ATP) |

She is hospitalized with signs and symptoms of right heart/Fontan failure including protein-losing enteropathy and is noted to be in a persistent AT at 125 bpm (cycle length 480 ms). Interestingly, her device has not detected AT and had not delivered atrial ATP. Fig. 1, panel A shows a surface ECG tracing of the presenting AT with 1:1 ventricular conduction, panel B shows the ongoing rhythm at device interrogation, panel C showing the underlying AT on suspension of atrial pacing, and panel D showing termination of AT with delivery of ATP through the programmer. (i) Why has the device not detected AT and delivered atrial ATP? (ii) What is the best solution to enable ATP for such AT episodes in the future?

Discussion

Different manufacturers have different algorithms for classifying AT/AF for switching to a non-tracking mode or delivery of atrial tachyarrhythmia therapy like ATP [1–4]. Most current generation Medtronic devices use the AT/AF Evidence Counter (Fig. 2, panel A) that keeps a log of V–V intervals with >1 atrial sensed events including atrial events sensed during atrial blanking and refractory periods. Every V–V interval with >1 atrial sensed event increases the counter by one, unless the extra atrial sensed events are classified as far-field R wave oversensing (usually during the atrial blanking period) using another algorithm based on the timing pattern of atrial events. Following an increment due to a V–V interval with >1 atrial sensed events, the subsequent V–V interval further increments the counter by one, even with a single atrial event. This is done to avoid underdetection of AT/AF due to undersensing or slower tachycardias. However, to compensate for this increment with only one atrial event in a V–V interval, if the next V–V interval has ≤1 atrial events the counter decreases by one. The AT/AF Evidence Counter is reset to 0 with delivery of atrial tachyarrhythmia therapy, any time there are 5 consecutive V–V intervals with ≤1 atrial events, or if there is evidence of sinus rhythm with far field R-wave oversensing.

When the pacemaker is programmed in a tracking mode that tracks atrial events in the ventricle, switch to a non-tracking mode is required in event of an AT/AF episode to prevent rapid ventricular pacing rates. This mode switch is effected once the AT/AF Evidence Counter reaches 3 if, in addition, the median PP interval (preceding 12 atrial events) is shorter than the programmed mode-switch interval (Fig. 2, panel B). If AT/AF is ongoing, the AT/AF Evidence Counter continues to accrue increments. The rhythm is classified as AT/AF once the counter is at ≥32 if the median PP interval is also shorter than the programmed AT/AF detection interval. Following further elapse of the detection interval the programmed therapy (ATP) is delivered if both the counter continues to be ≥32 and the median PP interval is shorter than the detection interval.

It is easy to see why AT detection fails in a single chamber pacing mode like AAIR. With no programmed ventricular pacing or sensing, the prerequisite V–V intervals are not generated. The AT/AF Evidence Counter algorithm requires these V–V intervals and checks for intervals with >1 atrial sensed events for diagnosis of AT/AF. This algorithm depends on more atrial events than ventricular events for diagnosing AT/AF. If there was a true ventricular lead, an AT with 1:1 atrioventricular conduction will not be classified as AT/AF as each V–V interval will have exactly 1 atrial event.

Fig. 3 shows the presenting rhythm and overlays the timing counters for two cycles of repeating events. As mentioned before, the ventricular port on the pacemaker is plugged and the ventricular paced events are inconsequential with respect to actual ventricular activation. The underlying rhythm is atrial tachycardia with cycle length of 480 ms (125 bpm). The first atrial sensed event (AS) is tracked by ventricular paced event (VP) after sensed AV delay (150 ms). The next atrial sensed event (TS) is tracked by ventricular paced event after a longer AV interval to comply with maximum tracking rate (MTR, 545 ms/110 bpm), thus causing pacemaker Wenckebach. The next atrial sensed event is not tracked as it falls in the post-ventricular atrial refractory period (PVARP, functional undersensing). Ventricular pacing at Wenckebach upper rate causes a switch from atrial-based to ventricular-based timing cycle (modified atrial-based timing cycle) and the next atrial pacing (AP) is delivered after elapse of the VA or atrial escape interval (LRL – paced AV delay = 800–180 ms = 620 ms) [5]. This atrial paced event is followed by a compensatory pause and the cycle of events continues to loop over. The phenomenon of escape atrial pacing following non-tracked atrial beats in PVARP is not uncommon in dual chamber devices and is a cause of failure to switch to a non-tracking mode during atrial tachyarrhythmias, although some algorithms (Filtered Atrial Rate Interval, St. Jude Medical Inc., St. Paul, Minnesota) [1] do not exclude the paced atrial events when counting towards atrial tachyarrhythmia detection.

As seen in Fig. 3, following the non-tracked atrial sensed event in PVARP, the relatively shorter atrial escape interval leads to an atrial paced complex before the relatively slow next AT beat is sensed. This leads to a single atrial sensed event in this V–V interval. The other V–V intervals are due to ventricular tracking of atrial sensed events and have 1:1 AV relationship. As a result, there are no V–V intervals with >1 atrial sensed events. Therefore, the AT/AF Evidence Counter
does not increment and mode-switch (count ≥3), classification of rhythm as AT/AF (count ≥32), or delivery of atrial ATP does not occur.

Knowledge of the AT/AF detection algorithm, as discussed above and shown in Fig. 2, facilitates understanding and troubleshooting of the presented problem. An option is to decrease the lower rate limit in the DDDR mode. This would increase the atrial sensing window (end of PVARP to atrial escape/VA interval) to preferentially facilitate detection of the next AT beat following a non-tracked beat in PVARP rather than deliver atrial pacing. However, the patient needs the programmed lower rate (75 bpm) for symptomatic benefit.

The best solution is to program to a non-tracking DDIR mode with shortest allowed AV delay (30 ms) and PVARP (150 ms). The DDIR mode precludes ventricular tracking of the atrial tachycardia at the maximum tracking rate, thus
Fig. 2 – Panel A – Flow diagram describing the functioning of AT/AF Evidence Counter (Medtronic Inc, Minneapolis, Minnesota) for detection of atrial tachycardia/fibrillation for mode switch and delivery of atrial tachyarrhythmia therapies. Atrial sensed events include those in blanking or refractory periods. AT/AF, atrial tachycardia/atrial fibrillation; V-V interval, ventriculo-ventricular interval. Panel B – A schematic showing the utilization of the AT/AF Evidence Counter (Medtronic Inc, Minneapolis, Minnesota) for mode-switch, AT/AF detection and delivery of atrial tachyarrhythmia therapies. AT/AF, atrial tachycardia/atrial fibrillation; PP, interval between 2 consecutive atrial paced/sensed events.
maintaining longer V–V intervals with higher chances of >1 atrial sensed events. The short AV delay and PVARP minimize the total atrial refractory period and lengthen the atrial sensing window. This maximizes the opportunity to sense intrinsic AT beats during the atrial sensing window prior to the elapse of the ventricular-based timing cycle, and inhibit atrial pacing (DDIR mode uses ventricular-based timing cycles for atrial pacing) [5]. It is worth mentioning that in the absence of a ventricular lead, there is no deleterious effect of having a short AV interval, PVARP or a non-tracking pacing mode. The severe sinus node dysfunction in this case circumvents the issue of inappropriate detection and therapies for AT/AF due to sinus tachycardia.

In summary, atrial ATP is useful in complex congenital heart disease patients as they are prone to poorly tolerated recurrent macroreentrant atrial tachycardias that can be difficult to ablate [6,7]. Need for atrial ATP in absence of a ventricular lead is a unique situation when a dual chamber mode has to be programmed in Medtronic devices to fabricate V–V intervals. This allows the device to apply the AT/AF Evidence Counter algorithm that detects atrial tachyarrhythmias. Notably, as this algorithm requires presence of V–V intervals with >1 atrial events, a 1:1 conducted AT will not be detected by a dual-chamber device with a functional ventricular lead [3,7]. The details of this algorithm and the recognition that AV delay, PVARP and ventricular tracking are superfluous in absence of a ventricular lead are critical when programming the pacing parameters to maximize chances of detecting atrial tachyarrhythmias. As a corollary, PVARP is also irrelevant in patients with dual chamber devices with no VA conduction, and it can be minimized to prevent failure of tracking of atrial complexes.

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