INTRODUCTION
When one interfaces the very precise behaviors of a dual chamber pacemaker with the intrinsic but sometimes difficult to quantify conduction and refractory periods in the human heart, a variety of rhythms can occur that can result in significant symptoms even though the pacemaker is functioning in a normal manner. This paper will specifically focus on the two major rhythms associated with retrograde conduction [1-4].

PACE MAKER MEDIATED TACHYCARDIA
A pacemaker mediated tachycardia (PMT) is a pacemaker associated tachycardia that is maintained by the continued active participation of the pacemaker in a dual channel pacing system. Technically, a PMT could be a period of rapid ventricular pacing while tracking an intrinsic atrial tachyarrhythmia such as atrial fibrillation or atrial flutter when intrinsic AV block would be associated with a slower intrinsic heart rate if not for the pacemaker. The usual PMT is associated with retrograde conduction from the ventricular paced beat to the atrium where the P wave is sensed by the pacemaker to trigger the next ventricular paced beat. A more precise term for this form of PMT is endless-loop tachycardia (ELT) [5-7].

Critical to an ELT is the ability of the heart to sustain conduction from the ventricle to the atrium (VA or retrograde conduction) with a sufficiently long “VA” interval such that the retrograde P wave coincides with the atrial alert period of the pacemaker allowing it to be sensed to thus trigger the next ventricular output. While retrograde conduction can occur in patients with anterograde AV block, it is far more common in patients whose pacemaker is implanted for sinus node dysfunction. As such, when the pacing system is functioning properly, it will usually appear to be single chamber atrial pacing with intact AV nodal conduction (Figure 1).

While most individuals with a normal conduction system have the ability to conduct in a retrograde direction, this does not occur with each and every beat because the normal atrial depolarization and the normal AV nodal conduction renders both those tissues physiologically refractory. A period of AV dissociation is required to catch both the atrial and AV nodal tissue physiologically recovered to allow retrograde conduction to occur. The next ventricular beat is then able to conduct...
retrograde. If the VA conduction interval is sufficiently long such that the retrograde P wave occurs at a time when the atrial tissue is physiologically recovered, it results in a depolarization which is sensed to then trigger the next ventricular paced beat.

The usual trigger for a PMT is a premature ventricular complex (PVC) but it could also be an atrial premature beat that coincides with a unique timing period in the pacemaker termed the Post-Ventricular Atrial Refractory Period, atrial undersensing or atrial loss of capture.

Figure 2 shows the initiation of a PMT by the intentional temporary reduction of the atrial output to a subthreshold level thus allowing retrograde conduction to occur. The atrial and ventricular outputs are bipolar resulting in a diminutive pacing stimulus artifact on the ECG.

This is most effectively shown on recordings from the pacemaker as displayed on the pacemaker programmer in conjunction with telemetered electrograms and event markers (Figure 3).
There are two timing intervals that are critical to a PMT. One is the Post-ventricular Atrial Refractory Period (PVARP). If this is sufficiently long, the retrograde P wave (AS) will coincide with the PVARP and while it may be sensed for purposes of identifying a rapid atrial rhythm, it will not be used to trigger a ventricular paced beat (VP) [8]. If sensed in the alert period, AS, it will be tracked to trigger a ventricular paced beat. In most PMTs, the AS complex occurs sufficiently early such that the AV node is still physiologically refractory from the retrograde P wave so that anterograde conduction cannot occur to result in a native ventricular depolarization (VS). The sensed AV delay is initiated but it ends before the maximum tracking rate interval (MTRI) has ended. As such, the resultant VP event is delayed until the maximum tracking rate interval (MTRI) has timed out. This, in turn, gives the atrium time to recover allowing the ventricular paced beat to again conduct retrograde. The relationship of the key timing intervals in the pacemaker to native events is shown in Figure 3. Since conduction from the atrium to the ventricle does not occur through the intrinsic tissues, this is shown as a dotted line. Actual conduction or paced events are shown as a solid line. There is conduction through the AV nodal tissue in a retrograde direction, from the ventricle to the atrium. This takes sufficiently long so that the resultant retrograde atrial depolarization shown as an upward directed arrow occurs after the PVARP ends, the retrograde P wave is sensed by the atrial channel of the pacemaker to trigger the next ventricular output.

A number of techniques are available to either prevent or recognize and terminate the PMT. To prevent the PMT from occurring, one need only program the PVARP to be greater than the VA conduction interval. This is the usual mechanism that is used as VA conduction is usually less than 300 ms but in some cases, the VA conduction interval is so long that programming a sufficiently long PVARP combined with a long AV delay to allow for intact conduction will limit the maximum tracking rate that can be programmed.

The second technique utilizes a PMT recognition and termination algorithm [9-11]. These have become increasing sophisticated over the years. A current iteration of such an algorithm identifies the rhythm as being a "PMT" based on "n" number of cycles of AS-VP at the maximum tracking rate or above a predefined rate that is lower than the MTR.

The algorithm starts measuring the VP-AS interval once the AS-VP rate exceeds a programmed value. If the VP-AS interval is stable, the rhythm is labeled a possible PMT. The algorithm then either shortens or lengthens the AS-VP interval on the next cycle. If the atrial rhythm is due to an intrinsic atrial tachycardia including sinus tachycardia, the VP-AS interval on the next cycle will change by the same degree to which the AS-VP was altered. If the rhythm is truly a PMT, namely the atrial sensed event (AS) is a result of retrograde conduction from the ventricular paced beat, the VP-AS interval will remain stable. The rhythm is then labeled a "probable PMT" and one of three behaviors, depending on the model, is possible. The PVARP can be extended to functionally block detection of the retrograde P wave for one cycle, the ventricular output may be withheld since the retrograde P wave is dependent on the ventricular paced beat or the ventricular output is withheld but as this may cause a significant pause with its own resultant adverse effects, an atrial stimulus is delivered 330-350 ms after the detected P wave. This interval is usually sufficient for the atrial myocardium to recover. The atrial stimulus causes an atrial depolarization rendering the atrial tissue refractory to a subsequent retrograde conduction and pauses are avoided.
Figure 4 is a 12 lead ECG capturing a PMT in progress with abrupt termination of the PMT by a PMT detection and termination algorithm.

![Image of Figure 4](image1.png)

**Figure 4.** Is a 12 Lead ECG. The changing morphology of the PMT complex is due to the changes in the recording lead. The Lead II rhythm strip along the bottom of the recording is continuous and shows a stable paced ventricular morphology during the PMT.

Figure 5 is a recording from the pacemaker programmer with a single surface lead, event markers and the atrial and ventricular electrograms. The behavior is more readily visualized.

![Image of Figure 5](image2.png)

**Figure 5.** The numbers represent millisecond intervals automatically calculated by the programmer. The top number represents the AS-VP (PV) or AP-VS (AR) interval. The middle number represents the functional VA interval and the lower number represents the VV or RR interval. In this case, the algorithm involves adjusting the PV interval on the next to last cycle (it is shortened from 290 ms to 240 ms, a shortening of 50 ms) but the VP interval is stable (± 25 ms). This labels the rhythm as a probable PMT and a ventricular output is withheld following the ensuing sensed P wave. This is followed 350 ms later by a paced atrial event (A or AP), the PMT is terminated and atrial pacing with intact AV nodal conduction resumes.

One should suspect a PMT when there is the abrupt onset of a tachycardia initiated by either a PVC, an APC, intermittent loss of atrial capture that then runs significantly faster than the prior rate, be it atrial paced or sensed or follows intermittent AV interval extension as with AV hysteresis algorithms. The rate will commonly be equal to the programmed MTR but it may be slower. If one has either an ECG that can display markers to represent pacemaker pulses (as in Figures 1 and 2 where the markers are located along the top of the recording) or a pacemaker programmer capable of displaying event markers with alphanumeric labels, the diagnosis should be suspected and can often be proven. Management usually requires increasing the PVARP or enabling one of the automatic PMT detection and termination algorithms.

To evaluate the patient for PMTs, the following is the technique that I utilize. I do not program the pacing mode to VVI at a higher rate for while this may demonstrate retrograde conduction, it does not allow one to evaluate whether the retrograde conduction is able to be sustained at a higher rate. Rather, the evaluation is performed in the dual chamber (DDD) mode with the following settings enabled as temporary parameters.

- **Mode:** DDD
- **Base Rate:** 10-15 bpm faster than the intrinsic rate
If the patient can sustain retrograde conduction, the resultant PMT will identify the V-A (retrograde conduction) interval to help guide programming PVARP. The V-V interval will identify the PMT rate to guide selection of the PMT detection rate which should be 10-15 bpm below the actual PMT rate. When the patient is in a sustained PMT, I then enable the PMT detection and termination algorithm to document that the algorithm functions properly in the specific patient. The desired parameters are then enabled on a permanent basis.

In some cases, the VA interval is so long that programming a sufficiently long PVARP will seriously limit the maximum tracking and maximum sensor rates. In those cases, I program a short PVARP while enabling the AutoDetect algorithm.

Sometimes, it may be helpful to program a very high maximum tracking rate for even though retrograde conduction may be present at lower rates, the higher rates induce retrograde conduction block or fatigue such that a PMT cannot be sustained. Figure 6 is an example of a patient with retrograde Wenckebach precluding a sustained PMT.

This, as with the examples shown in the 12 lead ECGs, was induced at the time of follow-up with a subthreshold atrial output.

Note that the first VP (VP-AS) interval is roughly 260 ms, the second is 280 ms and then the patient cannot conduct retrograde on the third ventricular paced complex. Hence, this patient can be programmed with a short PVARP if desired to allow a higher maximum tracking rate without concern about a sustained PMT. Even if there is total retrograde block, I tend to enable the AutoDetect algorithm simply because retrograde conduction, like anterograde conduction, may wax and wane.

REPETITIVE NON-REENTRANT VENTRICULO-ATRIAL SYNCHRONY (RNRVAS)
The other side of a PMT is a rhythm called "Repetitive Non-Reentrant Ventriculo-Atrial Synchrony" or abbreviated RNRVAS. Like a PMT, it requires intact retrograde conduction but in this case, the PVARP is sufficiently long precluding the device from tracking the retrograde P wave. The basic rate also tends to be faster but this is due to a high programmed base rate, rate modulation or any of the various atrial overdrive algorithms available from many different manufacturers with the goal of preventing a variety of atrial tachyarrrhythmias, most commonly atrial fibrillation. Unlike a PMT, this does not represent a re-entrant rhythm. Rather, the ventricular paced beat is associated with retrograde conduction but the PVARP is sufficiently long such that the P wave coincides with the PVARP and is not tracked. In most devices, intrinsic events coinciding with a refractory period in the pacemaker such as a P wave coinciding with the PVARP are not used to adjust timing interval. Thus, while the retrograde P wave is not tracked, it also does not inhibit or otherwise reset the atrial pacing stimulus. The intrinsic P wave, be it anterograde or retrograde renders the atrial tissue physiologically refractory. In view of the high paced rate or a very long physiologic atrial refractory period, the atrial output is delivered at a time when the atrial tissue is physiologically refractory. The failure to inhibit the atrial output due to the intrinsic P wave coinciding with the PVARP is termed "functional undersensing." The failure of the atrial stimulus to capture due to the atrial tissue being physiologically refractory is termed "functional loss of capture." Since the retrograde P wave occurs

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Setting</th>
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<tbody>
<tr>
<td>PVARP</td>
<td>As short as possible</td>
</tr>
<tr>
<td>MTR</td>
<td>As high as possible</td>
</tr>
<tr>
<td>PMT algorithm</td>
<td>Disabled</td>
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<tr>
<td>Atrial output</td>
<td>Subthreshold</td>
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too early in the cardiac cycle to be conducted in an anterograde manner and since the atrial stimulus does not capture, the programmed AV delay times out and a ventricular stimulus is delivered at the end of the programmed AV delay [12-14].

Using the same patient in whom the PMT was demonstrated, the base rate was increased, the atrial output was transiently reduced to enable retrograde conduction but the PVARP had been increased to prevent a PMT. Despite increasing the atrial output to its normal level (> 4:1 safety margin for capture), an RNRVAS rhythm ensued. Given that the atrial stimulus was not visible on the first recording that was obtained (Figure 7), a recording from a second patient was obtained with the atrial output was programmed to the unipolar configuration resulting in a large very visible stimulus. This is shown in Figure 8. The key to suspecting RNRVAS on either a 12 lead ECG or any monitoring system (telemetry, Holter) is a visible atrial stimulus which would not be present during a PMT since that is a tracking arrhythmia, loss of atrial capture and full ventricular capture even if retrograde atrial activation is not visible on the ECG.

![Figure 7](image1.png)

**Figure 7.** Apparent single chamber ventricular pacing. The retrograde P wave is not visible except for a slight deformity on the upstroke of the ST-T wave in Lead II and the atrial stimulus is not visible. Unless prior tracings were available, this would be interpreted as a VVI pacing system.

![Figure 8](image2.png)

**Figure 8.** This rhythm was recorded from a second patient but in this case, the atrial output was programmed to the unipolar output configuration resulting in a very obvious stimulus artifact. The long AV delay is not associated with capture. In this example, the retrograde P wave is more readily visible in the upstroke of the ST-T wave in Lead II. It is less than 200 ms before the delivery of the atrial stimulus. The retrograde P wave renders the atrial tissue physiologically refractory, 200 ms is insufficient time for the atrial tissue to recover resulting in a functional loss of capture associated with the atrial stimulus which was programmed to an output 4 times greater than the measured capture threshold performed earlier in the evaluation.

As with the PMT, the key events are most readily demonstrated using the pacemaker programmer monitoring one or more surface ECG leads, event markers and atrial and the ventricular electrograms. This is shown in Figure 9.
A combination of settings will predispose to the RNRVAS rhythm. First is the ability to sustain retrograde conduction. Second is a sufficiently long PVARP such that the retrograde P wave coincides with the PVARP and thus will not be tracked. Third is a sufficiently rapid atrial paced rate combined with a sufficiently long atrial physiologic refractory period. This way, the retrograde P wave renders the atrial tissue physiologically refractory precluding capture with the atrial stimulus. The sufficiently rapid atrial rate may be due to a high programmed base rate, rate modulation or an atrial overdrive algorithm as is available from many different manufacturers such as SJM’s AF Suppression algorithm.

As with a PMT, the most common trigger is a PVC as shown in Figure 10.
If it is known that the trigger for RNRVAS is isolated PVCs, enabling the +PVARP on PVC algorithm unique to St. Jude Medical dual chamber pacemakers will prevent the rhythm from even starting. This algorithm is more than a simple extension of the PVARP following a PVC in that it adds an additional alert period after the extended PVARP ends providing the atrium time to recover. Hence, the atrial escape interval after a PVC when the +PVARP on PVC algorithm is enabled is 830 ms. This will provide sufficient time for the atrial tissue to recover following the retrograde P wave and thus, when delivered, the atrial stimulus will capture the atrium.

RNRVAS is a common trigger for automatic mode switching (AMS) because all the atrial events are used to calculate either the filtered atrial rate interval (FARI) or capture “x” cycles of rapid atrial events. Once AMS is initiated, it will also effectively stop RNRVAS because entry into AMS also shortens the PVARP to equal the PVAB and inhibits the atrial output due to the P wave now being sensed in the atrial alert period. As such, AMS is also a mechanism to terminate RNRVAS if and when it occurs as shown in Figure 11.

The automatic AV interval extension algorithm can also predispose to either a PMT or RNRVAS in that a long AV delay (PR interval) for any reason may predispose to retrograde conduction [16-17]. The example shown in Figure 12 was recorded during a clinic visit in a patient implanted with a SJM Victory programmed to an AV/PV delay of 250/200 ms with a Ventricular Intrinsic Preference (VIP) delta of 200 ms. Three cycles of extended AV delay were programmed before the system would revert to the programmed paced and sensed AV delays. An atrial premature beat (P or AS) occurs and is followed by ventricular pacing 400 ms later. This is followed by atrial pacing with an AV delay of almost 350 ms this cycle is then associated with retrograde conduction. There is a brief period of RNRVAS type rhythm until the AV delay shortens, this effectively extends the atrial escape interval providing time for the atrium to physiologically recover such that RNRVAS is terminated because of atrial capture.

**COMMENT:**
A PMT is usually recognized and easily managed as discussed above. RNRVAS is less frequently recognized and may be more common today in association with long programmed paced and sensed AV delays and various mechanisms to increase the atrial paced rate. Functional RNRVAS may occur in the absence of retrograde conduction where the sinus rate is sufficiently fast such that it exceeds the maximum sensor rate of the pacemaker, coincides with the PVARP but the sensor or some other overdrive algorithm has also accelerated the atrial paced rate resulting in this juxtaposition of paced and sensed events to cause this rhythm, if only for a few cycles. As with a PMT where the most common cause is a PVC, the same holds for RNRVAS when the rate is already rapid and a PVC occurs that is associated with a retrograde P wave. If PVCs are known to be a common trigger, one can use the +PVARP on PVC algorithm if the pacemaker has this algorithm because the cycle following the PVC (associated with an increase in the PVARP and the addition of an atrial alert period) will usually result in the delivery of an atrial stimulus that will capture the atrium precluding RNRVAS from even beginning. RNRVAS is one of the causes of inappropriate AMS. However, entry into AMS also shortens the PVARP to equal the PVAB and inhibits the atrial output due to the P wave now being sensed. As such, AMS is also a mechanism to terminate RNRVAS if and when it occurs.
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