Automatic Mode Switching: Algorithms

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ABSTRACT

Dual chamber pacemakers having automatic mode switching can protect a patient from rapid ventricular pacing during supraventricular tachycardia. In this paper, automatic mode switching mechanisms will be overviewed.

KEYWORDS

Dual chamber pacemakers, automatic mode switching, atrial fibrillation

Otomatik Mod Değişikliği: Algoritmalar

ÖZET

Otomatik mod değişikliği özelliği bulunan iki odacıklı kalıcı kalp pilleri hastayı supraventiküler taşikardi sırasında oluşabilecek hızlı ventriküler pacingden korur. Bu yazida otomatik mod değişikliği mekanizmaları incelenecektir.

Anahtar Kelimeler

İki odacıklı kalp pilleri, Otomatik mod değişikliği, atrial fibrilasyon,
Dual chamber pacemakers equipped with automatic mode switching (AMS) can protect a patient from rapid ventricular pacing by automatically functioning in a non-atrial tracking mode (VVI, VVIR, DDI, DDIR) during supraventricular tachycardia (SVT). AMS requires fundamental changes in the operation of pacemaker timing cycles to maximize SVT detection above the programmed upper rate (Fig 1). Although many of the AMS algorithms from a variety of manufacturers are device-specific, the actual timing cycles required for SVT detection are basically independent of AMS algorithm design. For appropriate SVT detection the atrial signal should be of sufficient amplitude and the obligatory blanking periods (when the sensing amplifier is temporarily disabled) should be restricted to a small fraction of the pacing cycle. Blanking periods cannot be eliminated because they prevent oversensing of undesirable signals inherent to all pacing systems.

Appropriate AMS depends on several parameters: a) the programmed detection rate; b) atrial sensing and the characteristics of the arrhythmia; c) the characteristics of the AMS algorithm. AMS failure may occur if the amplitude of the atrial electrogram is intermittently or consistently too small to be sensed or if an atrial signal occurs systematically during the atrial blanking period. An AMS algorithm can provide important data about SVT: onset, AMS response, and resynchronization. Since AMS programs al-

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**FIGURE 1**

*Basic timing cycles related to automatic mode switching*
so provide data on the time of onset and duration of AMS episodes, AMS data may be considered a surrogate marker of SVT recurrence. Stored electrograms have enhanced the accuracy of AMS in detecting SVT. The total duration of atrial fibrillation (AF) is correctly represented by the total duration of AMS and can be considered a reliable measure of total AF duration. Automatic mode switching algorithms, which provide data on the time of onset and duration of AMS episodes, allow a more accurate determination of the proportion of time a patient with AF is in AF and have led to the concept of “AF burden.” On the other hand, atrial tachycardia duration is poorly correlated with AMS duration. The extremely high sensitivity and specificity of AMS for AF is clinically useful for assessing the need for anticoagulation and/or the necessity or efficacy of antiarrhythmic therapy.

The prevalence of recurrent AF, particularly asymptomatic episodes are easily underestimated. Asymptomatic AF is far more common than symptomatic AF. This has important implications for anticoagulation therapy. Furthermore, AMS events may serve as a valuable tool for studying the natural history and burden of SVT even in asymptomatic patients.

**AMS Algorithms**

A “rate cut-off” criterion is commonly used in pacemakers to activate automatic switching (AMS) in the form of a sensed atrial rate exceeding a programmable value (for a defined period of time or cycles). The atrial rate is continuously monitored by increasing/decreasing counters or by consecutive rapid atrial events counters. AMS is activated when the count of the short atrial cycles exceeds the programmed cut-off criterion. Many Medtronic pacemakers activate AMS after detecting 4/7 atrial intervals shorter than the tachycardia detection interval (Figs 2-4). In one system atrial events above the

![Medtronic algorithm for mode switching](image)
tachycardia detection rate, increment the detection counter, whereas events below the tachycardia detection rate decrement the counter (Boston Scientific). Atrial tachyarrhythmia is detected when the counter reaches a fixed value (Fig 5-7). AMS then occurs over a programmable time between 1 and 5 minutes.

Another algorithm uses a “running average” rate as a criterion to move towards AMS (Early Medtronic and current St Jude devices) (Figs 8-10). This mechanism (“mean, filtered, or matched atrial rate”) is based on a moving value related to the duration of the prevailing sensed atrial cycle. AMS will occur when the “filtered” interval shortens to the tachycardia detection interval. In St Jude devices AMS requires the FARI (Filtered Atrial Rate Interval) to shorten to the programmed Atrial Tachy Detection Rate (interval) “ATDR”. FARI is adjusted with every atrial sensed and paced event including atrial sensed events in the unblanked portion of the postventricular atrial refractory period (PVARP). So, all p-p (p = atrial depolarization), p-A (A = atrial paced event), A-p and A-A intervals are counted towards the averaged FARI. In other words, all atrial intervals are counted. The averaging algorithm takes the current paced rate, estimates the FARI and then shortens FARI by 39ms for every atrial interval shorter than FARI. It lengthens FARI by 25ms for every atrial interval longer than FARI. Because the process is gradual, the rapidity of AMS will depend on the pre-existing sinus rate and the atrial tachycardia detection interval. It is faster for the filtered atrial interval to reach the tachycardia detection interval when atrial tachycardia starts in the setting of a higher resting sinus rate (shorter filtered atrial rate interval) than from a sinus bradycardia.

**Detection of Atrial Flutter by Dual Chamber Pacemakers**

Patients with paroxysmal atrial flutter represent a challenge for AMS algorithms. AMS failure may occur during atrial flutter when alternate flutter waves coincide with the post-
If “Post Mode Switch Overdrive Pacing” (PMOP) is not programmed, after the atrial tachyarrhythmia ends, the pacing rate is smoothly varied until the rate corresponds to the intrinsic atrial rate. Then the pacemaker switches to the programmed atrial tracking mode. To avoid an abrupt drop in the ventricular rate at the onset of AMS, the pacemaker smoothly reduces the pacing rate from the atrial synchronous rate to the sensor-indicated rate over several pacing cycles.

AMS termination: when at least seven A-A intervals longer than the upper tracking rate interval or when five consecutive atrial paces occur, the pacemaker assumes atrial tachyarrhythmia has ceased and begins to switch back to the programmed atrial tracking mode.

“Post Mode Switch Overdrive Pacing” (PMOP) allows mode switch to provide extended DDIN pacing at a higher rate after the atrial arrhythmia subsides. In PMOP, after the programmed Overdrive Period (at a programmed Overdrive Rate) has elapsed, the pacemaker returns to tracking in the atrium in DDIN or DDD mode as originally programmed. If PMOP is programmed, after the atrial tachyarrhythmia ends, the pacing rate is smoothly modulated until the programmed Overdrive Rate is reached. The pacemaker maintains the Overdrive Rate in DDIN mode for a programmed duration (Overdrive Period). When the Overdrive period expires, the rate is gradually modulated until the Lower Rate or Sensor Rate is reached, and then the pacemaker switches back to the programmed atrial tracking mode.

ventricular atrial blanking period (Fig 11). In some designs, the duration of the blanking periods prevents the pacemaker from detecting atrial flutter, if the atrial cycle does not match the sensing window of the atrial channel. In other words, the duration of the PVAB imposes mathematical limits on the detection of atrial flutter. If AV interval + PVAB > atrial cycle length (P-P or f-f interval), the pacemaker will exhibit 2:1 atrial sensing of atrial flutter (2:1 lock-out).
**AMS or ATR Programmable Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Programmable Values (Insignia model)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trigger Rate AT detection rate</td>
<td>Rate cutoff at which the pacemaker defines detected atrial rate as a tachycardia</td>
<td>100-200 ppm Nominal = 170 ppm</td>
</tr>
<tr>
<td>Entry Count</td>
<td>Number of atrial cycles (not consecutive) at or above the ATR Trigger Rate required to initiate Duration and the Exit Counter</td>
<td>1-8 cycles Nominal = 8 cycles</td>
</tr>
<tr>
<td>Duration</td>
<td>Number of ventricular cycles counted before Fallback Time and Fallback Mode are initiated</td>
<td>0-2048 cycles Nominal = 8 cycles</td>
</tr>
<tr>
<td>Fallback Mode (AMS mode)</td>
<td>The inhibited mode to which the device switches (&quot;mode switch&quot;) once Duration has been fulfilled, and remains in until Exit Count criteria are met</td>
<td>VDI(R), DDI(R) Nominal = VDI</td>
</tr>
<tr>
<td>Fallback Time</td>
<td>The time that the ventricular paced rate decelerates to the ATR Lower Rate Limit (LRL) or sensor-indicated rate</td>
<td>0-120 sec Nominal = 30 sec</td>
</tr>
<tr>
<td>ATR Lower Rate Limit (ATR-LRL.)</td>
<td>A separate programmed rate occurring during AMS (ATR). Fallback at which the ventricle is paced in the absence of sensed intrinsic ventricular activity</td>
<td>30-150 ppm Nominal = 70 ppm</td>
</tr>
<tr>
<td>Exit Count</td>
<td>Number of atrial cycles below the ATR Trigger Rate required to terminate Duration or Fallback Mode and return to the normal programmed mode</td>
<td>1-8 cycles Nominal = 8 cycles</td>
</tr>
</tbody>
</table>

**FIGURE 5**

*Nomenclature of mode switching function in Boston Scientific devices*

**FIGURE 6**

*Schematic representation of mode switching steps in Boston Scientific devices.*
Sensing of alternate atrial signals will occur if $AVI + PVARP < 2$ atrial cycles. Abbreviation of the PVAB may solve the problem provided far-field R wave sensing does not occur.

**Supplemental Algorithms For The Detection of Atrial Flutter**

Some devices provide additional algorithms to unmask the presence of “blanked” atrial flutter so
Behavior of the filtered atrial interval in a St Jude device (slowing atrial rate).

Diagrammatic representation of the mode switching function of St Jude devices.

Abbreviations: AMS = automatic mode switching; AP = atrial paced event; AS = atrial sensed event; ARI = atrial rate interval; ATDI = atrial tachycardia detection interval; ATDR = atrial tachycardia detection rate; FARI = filtered atrial rate; MTR = maximum tracking rate;
as to activate AMS (Figs 12). Medtronic provides an algorithm specifically designed for atrial flutter which automatically extends the PVARP for one cycle whenever the pacemaker senses detects an atrial cycle length less than twice (AV interval + PVAB) and the atrial rate is greater than half the tachycardia detection rate (or the atrial interval is less than twice the tachycardia detection interval). AMS occurs if an atrial event is sensed within the extended unblanked PVARP thereby revealing the true atrial cycle which terminates with the ensuing non-refractory sensed atrial depolarization.

Boston Scientific’s supplemental atrial flutter algorithm works by overlapping atrial blanking periods (Fig 13).

**Behavior of Atrial Refractory Period in Medtronic Devices During AMS**

When the mode switches to DDIR even from the DDD mode, the device uses sensor-varied PVARP. The sensor-varied PVARP in the DDIR mode tries to maintain a 300 ms atrial inhibition window (AIW). i.e., it tries to end the PVARP 300 ms before the scheduled emission of the atrial stimulus. The equation is: $PVARP = (\text{escape or sensor-indicated interval}) - (\text{paced AV interval}) - 300\text{ms}$. In terms of a sensor-indicated VA (or atrial) escape interval, the equation is: $PVARP = \text{escape VA} - 300\text{ms}$. If the calculation results in a value less than the PVAB, the pacemaker limits the PVARP to
the PVAB value (Fig 14). In other words, there would be no actual unblanked PVARP, only a PVAB and the AIW would become shorter than 300ms. The PVAB limit is reached by programming longer paced AV intervals. Parameters permit calculation of the PVAB limit. When the PVAB is at 180 ms, sensor-varied PVARP will reach the PVAB limit at a sensor rate of ~85 ppm (PVARP = 700–220–300 = 180 ms). When the PVAB is at 130 ms, sensor-PVARP will reach the PVAB limit at a sensor rate of ~92 ppm (PVARP = 650–220–300 = 130 ms). Thus, the PVARP decreases with a decrease in rate but as discussed below it increases with relatively slow rates.

On the other hand, when the sensor-indicated rate is 60 ppm (1000 ms) and the paced AV delay is set to 200 ms, the sensor-varied PVARP will be (1000-300-200) = 500 ms which is quite long (Fig 15). This creates a 300 ms sensing window prior to the scheduled atrial stimulus. This behavior (going to sensor-varied PVARP...
Algorithm for the detection of atrial flutter in Boston Scientific devices.

When AFR is programmed to 230 ppm (the maximum value), for example, a detected atrial event inside the PVARP or a previously triggered AFR interval will start an AFR window of 260 ms (230 ppm). Atrial detection inside the AFR will be classified as Refractory Sensed event and will not be tracked. The sensing window starts only after both the AFR and the PVARP have expired. Paced atrial events scheduled inside an AFR window will be delayed until the AFR window has expired. If there are fewer than 50 ms remaining before a ventricular pace, the atrial pace is inhibited for the cycle. The ventricular pace is not affected by AFR and will take place as scheduled.

Behavior of the PVARP during automatic mode switching

The pacemaker sees the true atrial flutter rate and mode switching occurred. When the mode switches to DDIR, Medtronic devices use sensor-varied PVARP even if the original mode was DDD. The sensor-varied PVARP attempts to maintain a 300 ms atrial inhibition window (AIN), i.e. it tries to end the PVARP 300 ms before the scheduled emission of the atrial stimulus. The equation is: PVARP = (escape or sensor-induced interval) - (paced AV interval) - 300 ms. If the calculation results in a value less than the PVAB, the pacemaker limits the PVARP to the PVAB value. In other words, at this point there would be no actual unblanked PVARP, only a PVAB and the AIN would become shorter than 300 ms. In the case shown in the figure, rate-adaptive AV delay was programmed at 220 ms with a start rate of 100 ppm. Consequently, the parameters permit calculation of the PVAB limit. With the PVAB at 130 ms, sensor-PVARP will reach the PVAB limit at a sensor rate of 92 ppm (interval = 680 ms). The equation is PVARP = 650 - 220 - 300 = 130 ms. With a VS-AS interval of about 150 ms as in the tracing, AS is sensed early (beyond the prevailing PVARP which is now shorter in the DDIR mode than the programmed value of 250 ms (but AR is detected in the unblanked portion of the atrial refractory period during AV (AS-VS) interval initiated by AS). A PVARP ≤ 160 ms would require a sensor-indicated rate of 88 ppm to explain the events in the tracing. The slight increase of the sensor-indicated pacing rate in the DDIR mode from 80 to 88 ppm (though unseen) can be explained by sensor activation from the pressure or manipulation of the programmer over the pacemaker.
during mode switch, maintaining a 300 ms AIW, and limiting the AIW when PVARP reaches PVAB) has been a Medtronic design in all bradycardia and tachycardia devices since the original Thera design.

**Behavior of Atrial Refractory Period in St Jude Devices During AMS**

During a mode-switch, the PVARP is replaced by the programmed setting of the postventricular atrial blanking period (PVAB). The lowest available PVAB period during a mode-switch (and thus, the lowest PVARP) is 110 ms. In other words, there is no unblanked PVARP.

Atrial tachycardia/atrial fibrillation (AT/AF) counter for AMS in Medtronic devices

Some Medtronic pacemakers and ICDs use an AT/AF evidence counter for AMS rather than the “4 out of 7” algorithm. It is basically an AF detection algorithm component of PR logic. AMS occurs when AT/AF evidence counter $^{3}$ 3 and the median P-P interval < AT detection interval.

Median atrial interval. The device continually updates the median atrial interval. This interval is calculated by finding the median of the 12 most recent intervals. The last 12 intervals are sorted in numerical order, and the median interval is the larger of the middle 2 values in the set. The median atrial interval must be less than the programmed AT/AF detection interval for AT/AF detection to occur.

AT/AF onset. AT/AF onset occurs when the
median atrial interval is less than the AT/AF detection interval and the AT/AF counter has counted (using PR Logic) at least 3 ventricular events in which the A:V pattern shows evidence of an atrial arrhythmia. The device begins storing episode data after AT/AF onset occurs.

AMS termination. The device identifies sinus rhythm using the sinus rhythm criterion of PR Logic. The termination sequence is more complex when there is an unclassified rhythm with a median atrial interval greater than the AT/AF detection interval.

**Retriggerable Atrial Refractory period**

Some pacemakers with a retriggerable or resettable atrial refractory period revert to the DVI or DVIR mode upon sensing a fast atrial rate. In such a system, an atrial signal detected in the PVARP beyond the initial PVAB does not start an AV interval but reinitiates a new total atrial refractory period (TARP) or the sum of AVI and PVARP. This process repeats itself so that SVT faster than the programmed upper rate (i.e., P-P interval < TARP) automatically converts the atrial channel to the asynchronous mode and the pacemaker to the DVI mode at the lower rate or the DVIR mode according to design and programmability. The concept of overlapping refractory periods is important in the ventricular channel of pacemakers to prevent continuous inhibition from rapidly recurring extraneous signals from interference.

Most illustrations are being published in the book titled “Cardiac Pacemakers and Resynchronization” second edition by S. Serge Barold, Roland X. Stroobandt and Alfons F. Sinnaeve (Wiley in press).
REFERENCES


