AAI(R)-DDD(R) Mode Switch Algorithms to Minimise Right Ventricular Pacing

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Word count (excluding title page and references): 2,114
References: 27
Images: 1

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Introduction

Right ventricular (RV) pacing results in ventricular dyssynchrony and is associated with a reduction in left ventricular (LV) function [1] and an increase in the risk of heart failure (HF) and atrial fibrillation (AF) [2]. For patients with an indication for bradycardia pacing, atrial-based pacing (atrial only or dual-chamber) has been shown to confer modestly improved prognosis compared to ventricular-based pacing, mainly through a reduction in new AF, and possibly a lower incidence of stroke, although there was no significant effect on HF across randomised-controlled trials (RCT) [3]. However, analysis of the MOde Selection Trial (MOST) demonstrated that the cumulative amount of RV pacing, rather than the choice of pacing mode, was an important determinant of HF outcomes, with >40% RV pacing conferring a hazard ratio of 2.99 (95% CI 1.15, 7.75) for HF hospitalisation in DDDR patients [2]. A similar observation was made in the Dual Chamber and VVI Implantable Defibrillator (DAVID) trial in ICD patients with impaired LV systolic function but without a bradycardia pacing indication, where patients in the DDDR group (lower rate limit (LRL) 70 bpm) with cumulative RV pacing >40% had significantly higher rates of
death and/or HF hospitalisation compared to those with <40% ventricular pacing in the DDDR group, or those randomised to backup VVI pacing (LRL 40 bpm) [4]. Furthermore, in patients undergoing AV node ablation for AF, RV-only pacing was shown to result in worsened LV systolic function compared to biventricular pacing [5].

As a result of these observations, attempts have been made to minimise RV pacing in pacemaker and ICD patients. There are 3 main strategies by which RV pacing can be reduced in dual chamber pacing systems:

1. DDD pacing with a fixed long AV delay
2. AV hysteresis
3. AAI(R)-DDD(R) mode switch algorithms

Although there is some clinical benefit (preservation of LV fractional shortening) reported in DDDR with a long AV delay compared to a short AV delay [6], the main disadvantage of a fixed long AV delay is that the total atrial refractory period (TARP) is prolonged, resulting in changes to upper rate behaviour (i.e. pacemaker Wenckebach and subsequently 2:1 block at lower atrial tracking rates, leading to exercise-induced AV block); if the post-ventricular atrial refractory period (PVARP) is shortened to compensate, this can predispose to pacemaker-mediated tachycardia. To combat these issues, AV hysteresis algorithms were introduced. These algorithms operate in DDD(R) mode, but continually ‘search’ for intrinsic conduction by extending the programmed AV delay by a set duration. In ICD patients, use of DDDR pacing (60-130 bpm) with AV hysteresis resulted in similar clinical outcomes to patients programmed to VVI pacing (40 bpm) [7], which in turn had previously been shown to be superior to standard DDDR pacing [8].

However, the newer AAI(R)-DDD(R) mode switch algorithms are thought to be the most effective algorithms to minimise RV pacing. These algorithms use a functional AAI(R) pacing mode, however the device continually monitors AV conduction on a beat-to-beat basis (therefore in reality they function in ADI(R) mode as both chambers are sensed). In the event of persistent loss of AV conduction the algorithm can switch to DDD(R) mode, but can revert to AAI(R) when conduction returns to minimise RV pacing. In this editorial I will summarise the mode of action of these algorithms specific to each manufacturer (Medtronic, Boston Scientific, Sorin and Biotronik) and review the evidence supporting their use.

**Medtronic**

The Managed Ventricular Pacing (MVP) algorithm by Medtronic is the most studied of the available mode switch algorithms. This algorithm works by utilising a default atrial-based pacing mode (AAI(R)) with automatic switch to DDD(R) mode if persistent loss of AV conduction is detected, defined as two of the most recent four A-A intervals with no ventricular sensed (VS) event. The criterion for intrinsic conduction is met if there is a VS event before the next atrial sensed (AS) or paced (AP) event. In the event of a missing VS, the device gives a backup ventricular stimulation following the next AS or AP, such that two consecutive missing VS events are not permitted, however single dropped beats, e.g. during Mobitz type 1 (Wenckebach) second degree AV block are permitted.
After switching to DDD(R), the pacemaker performs intermittent checks for return of AV conduction by inhibiting ventricular pacing for one cycle. The first check occurs after 1 minute, then at progressively longer intervals (2, 4, 8… minutes) up to a maximum of 16 hours. Thereafter the checks for intrinsic conduction occur every 16 hours. If return of intrinsic AV conduction is detected, mode switch back to AAI(R) mode occurs.

Figure 1

The ECG in Figure 1, recorded from a patient with a Medtronic Adapta DR pacemaker, demonstrates the MVP algorithm checking for intrinsic conduction. Such ECGs can be interpreted as pacemaker malfunction [9].

MVP was first tested in a small population of ICD patients with no previous history of AV block. In this randomised study, MVP significantly reduced cumulative ventricular pacing compared to fixed DDDR mode (4% vs. 81% respectively), with no adverse effects, and with similar rates of cumulative atrial pacing [10]. In a subsequent larger study with a similar design, MVP reduced cumulative ventricular pacing compared to DDD(R) by a similar margin in ICD patients [11]. In pacemaker patients, MVP was shown to significantly reduce cumulative ventricular pacing compared to DDD(R); unsurprisingly, patients with sinus node disease (SND) had a greater reduction than those with AV block (AVB) (median relative reduction 99% vs 60% respectively) [12]. In unselected pacemaker patients, MVP was able to reduce cumulative ventricular pacing to below the 40% threshold in 72% of patients overall (50% of AVB patients and 86% of SND patients) [13]. The algorithm has also been used successfully in paediatric patients and patients with adult congenital heart disease [14].

Despite the clear efficacy of MVP in reducing cumulative ventricular pacing, trials to show clinical benefit (in terms of reduction in HF and AF) have shown mixed results.
The SAVE PACe study demonstrated a significant reduction in new persistent AF in patients with SND and normal LV function randomised to either MVP or Search AV+ (Medtronic AV hysteresis algorithm) compared with conventional dual-chamber pacing (7.9% vs 12.7%), although there was no difference in HF hospitalisation or mortality [15]. MVP was subsequently shown to be more effective than Search AV+ in reducing RV pacing, particularly in patients with AV block [16]. However, in the large randomised MVP trial it was not possible to show equivalence of MVP to backup VVI pacing in ICD patients without a bradycardia pacing indication, with a trend toward increased mortality and/or HF events in the MVP arm [17]. Recently, the PreferMVP trial showed no clinical benefit of MVP compared to DDD pacing in patients already implanted with a pacemaker or ICD with >40% ventricular pacing who were scheduled for generator replacement [18]. However, the very recently published MiNimizE Right Ventricular pacing to prevent Atrial fibrillation and heart failure (MINERVA) trial showed that MVP in combination with atrial antitachycardia pacing (DDDRP mode) was superior to standard DDDR pacing in reducing progression to permanent AF in patients with bradycardia and previous atrial tachyarrhythmias [19].

Boston Scientific

The Boston Scientific RYTHMIQ algorithm utilises AAI(R) mode with concurrent VVI backup pacing at a rate 15 bpm below the LRL (i.e. as if there were two separate AAI and VVI pacemakers working concurrently, albeit with a different LRL). Thus, in contrast to MVP, it does not allow pauses due to unconduted atrial events. If there is persistent loss of AV conduction, defined as 3 out of 11 beats with VS or VP >150ms slower than the AAI(R) pacing rate, the device switches to DDD(R) mode. RYTHMIQ uses the Boston Scientific AV hysteresis algorithm (AV Search+) to detect return of AV conduction; if this algorithm remains in AV hysteresis for 25 cardiac cycles, and <2 of the last 10 cycles are VP, the device reverts to AAI(R) mode with backup VVI pacing.

In contrast to MVP, there is very little published data for the efficacy or clinical benefits of RYTHMIQ, or for the very similar Reverse Mode Switch (RMS) algorithm that preceded RYTHMIQ (the only difference being the addition of an atrial tachycardia response in AAI(R) mode). One small study has suggested that RMS may be prone to inappropriate mode switch to DDD(R) in the presence of ventricular ectopic beats, leading to reduced efficacy in minimising ventricular pacing [20]. More robust evidence exists for the AV Search+ (AV hysteresis) algorithm, as described above [7].

Sorin

The SafeR algorithm by Sorin (previously known as AAIsafeR and AAIsafeR2) switches from AAI(R) to DDD(R) if any of the following criteria are met:

- 2 consecutive blocked atrial events (3rd degree block criterion)
- 3 out of 12 blocked atrial events (2nd degree block criterion)
- 6 long sensed or paced AV intervals; maximal AV interval is programmable (1st degree block criterion)
- Ventricular pause greater than programmed pause duration (either 2, 3 or 4 seconds; safety criterion)
- >3 AAI(R) to DDD(R) mode switches during exercise (defined as heart rate >100 bpm (or >30 bpm above LRL if LRL >75 bpm)

Temporary reversion to AAI(R) mode occurs after 100 VP beats to check for return of intrinsic conduction, or if 12 consecutive conducted R waves are recorded. SafeR also allows for longer periods of DDD(R) pacing if frequent loss of intrinsic conduction occurs; the device will remain in DDD(R) until 8am the following day if any of the following criteria are met, unless 12 consecutive conducted R waves are recorded:

- 50% DDD pacing during one hour
- 45 AV block episodes within 24hrs
- 15 AV block episodes every 24hrs over 3 consecutive days

Small observational or non-randomised studies demonstrated the safety and efficacy of AAIsafeR and AAIsafeR2 in detecting unexpected AV block in SND patients [21,22] and reducing cumulative RV pacing compared to DDD(R) [23]. More recently, in the randomised Spontaneous AtrioVEntricular conduction pReservation (SAVE-R) trial of 422 patients with SND or intermittent AVB, those randomised to SafeR had significantly lower cumulative RV pacing after 1 year compared to either DDD with AV hysteresis or DDD with long AV delay (4.5% vs 37.9% vs 16.7% respectively), although there was no significant difference in the rates of persistent AF in this study [24].

**Biotronik**

The Vp Suppression algorithm by Biotronik uses DDD(R) mode initially. If a single VS event is detected, or if there is no intrinsic conduction for 30 seconds, the device enters a search phase where the AV delay is extended to 450 msec for 8 cycles. If the programmable intrinsic detection criterion is met (1-8 consecutive ventricular sensed events (nominal setting is 6)), the device switches to ADI(R) mode. If this criterion is not met, the device reverts to DDD(R), with the searching interval doubling each time up to a maximum of 128 minutes; thereafter the search for intrinsic conduction occurs every 20 hours.

In ADI(R) mode, intrinsic conduction is monitored within a 450 msec interval after each atrial event. A cycle without intrinsic ventricular conduction triggers a further 8-cycle evaluation period. If any of the following criteria are met, the device reverts to DDD(R):

- 2 consecutive cycles without intrinsic ventricular conduction
- a programmable number (1-8) out of 8 cycles without intrinsic conduction
- no VS event for 2 or more seconds
At present, there is no published data to support the efficacy of the Vp Suppression algorithm.

**Caveats regarding AAI(R)-DDD(R) mode switch algorithms**

The major disadvantage of these algorithms is that very long AV delays may be permitted (i.e. profound 1st degree AV block); this can lead to unfavourable haemodynamics due to AV dyssynchrony, including diastolic mitral regurgitation. MVP has been shown to result in significantly prolonged AV intervals (>300 msec) in a proportion of patients [25]. Furthermore, subgroup analysis of the MVP trial (discussed above) showed that the small increase in mortality/HF events in the MVP group was driven by an increase in events in the subset of patients with PR interval >230 msec [17]. Conventional DDD(R) pacing may be more appropriate for such patients. There have also been isolated reports of pro-arrhythmia [26,27], thought to be mediated via long AV intervals.

As pauses due to isolated unconducted atrial events may be permitted by these algorithms, the effective ventricular rate may fall to half of the programmed pacing rate. As such it is recommended to programme the lower rate limit no lower than 50 bpm in patients with frequent AV block. The algorithms are not recommended for patients with persistent 3rd degree AV block, or those with persisting baseline Mobitz type I (Wenckebach) 2nd degree AV block. A back-up dual chamber pacemaker programmed VVI at a low rate may be preferable in patients with AV block expected to have a very low pacing burden (e.g. trifascicular block with very infrequent syncope). As an individual patient’s underlying rhythm may change over the course of time (e.g. development of persistent rather than intermittent AV block), it is important to check the pacing mode at each pacemaker or ICD follow-up appointment to ensure that the pacing mode remains optimal.

**Conclusion**

There now exists a body of evidence to support the efficacy of AAI(R)-DDD(R) mode switch algorithms, especially MVP (Medtronic) and SafeR (Sorin), in reducing cumulative RV pacing in unselected pacemaker and ICD patients. Higher cumulative RV pacing percentages are associated with AF and HF events, however despite impressive reductions in cumulative RV pacing compared to other pacing modes, evidence of clinical benefit from these algorithms is still uncertain; there may be benefit in reducing AF burden, however reduction in mortality and HF has not been demonstrated.

**Acknowledgements**

I would like to thank Dr Adam Fitzpatrick for providing the ECG in Figure 1.

**References**


