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Upper rate behavior in six dogs with dual-chamber pacemakers☆

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Abstract *Introduction:* This report provides clinical examples of upper rate behavior in dogs with dual-chamber pacemakers, with suggestions for programming alterations to avoid detrimental upper rate behavior.
Animals: Six dogs with dual-chamber pacemakers displaying upper rate behavior at upper atrial tracking rates.
Methods: Medical records of dogs with dual-chamber pacemakers with evidence of upper rate behavior were reviewed retrospectively from two institutions. Two of the six dogs were followed prospectively, and 24 h Holter monitors were placed to evaluate upper rate behavior correlated to programming settings.
Results: Pacemaker Wenckebach or 2:1 atrioventricular block was documented in four of six dogs, and automatic mode switch was documented in two of six dogs. Twenty-four—hour Holter monitors placed on two dogs after pacemaker optimization documented a pacemaker Wenckebach window at increased atrial rates with neither dog reaching their respective 2:1 block point throughout the recording period.
Conclusions: Clinicians who implant dual-chamber pacemakers should be aware of upper rate behavior in animal species with high heart rates. Optimal programming of dual-chamber pacemakers can be achieved by selecting programmed timing

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intervals to limit deleterious upper rate behavior and create a more physiologic ventricular response at maximum tracking rates.

Abbreviations

AMS	automatic mode switch
ATA	atrial tachyarrhythmias
AV	atrioventricular
AVD	atrioventricular delay
PVARP	postventricular atrial refractory period
TARP	total atrial refractory period
URI	upper rate interval
URL	upper rate limit

Introduction

Several symptomatic bradyarrhythmias are treated by implantation of pacemaker systems in dogs [1,2]. Clinicians may consider a dual-chamber pacemaker when atrioventricular (AV) synchrony is desired [3–5]. Two common dual-chamber configurations include a dual (right atrial and right ventricular) lead system programmed in a DDD mode (dual chamber pacing and sensing, both triggered and inhibited mode) and a system of a single lead with floating atrial electrode programmed to VDD mode (ventricular pacing with atrial tracking) [3,6]. The clinical indications, implantation technique, and programming tips for VDD systems in the dog have been previously described [3,4,6–9] as well as extensively documented in the human literature [10–14]. Similar reports for DDD pacing in dogs have been reported [4,5]. As atrial rates increase in a patient with absent AV conduction and a dual-chamber pacemaker programmed in a tracking mode, such as DDD or VDD, the increase in atrial rate can result in upper rate behaviors. Broadly defined, upper rate behavior is a change in the ventricular response rate when the maximal tracking rate is exceeded and is determined by the total atrial refractory period (TARP) [15]. Because of the higher inherent heart rates in dogs compared with humans, upper rate behaviors are likely more common in canine patients. An understanding of timing intervals and upper rate behavior when programming dual-chamber pacemakers can optimize ventricular response for dogs experiencing higher atrial rates (Fig. 1).

This clinical study describes clinical examples of upper rate behavior in dogs, followed by a discussion of programming strategies in dual-chamber systems aimed at limiting detrimental upper rate behaviors including pacemaker Wenckebach, 2:1 AV block, and automatic mode switch (AMS). A brief overview of a treatment strategy using burst overdrive pacing for atrial tachyarrhythmias (ATA) in patients with dual-chamber pacemakers is also discussed.

Animals, materials and methods

Medical records from the Colorado State University Veterinary Teaching Hospital and The Ohio State University Veterinary Medical Center for dogs with dual-chamber pacemakers implanted between 2013 and 2018 with documented evidence of upper rate behavior were reviewed. The underlying rhythm diagnosis, age at diagnosis, pacemaker manufacturer, pacemaker programming settings, and documented upper rate behavior were recorded. Two dogs were then followed prospectively with physical examinations, electrocardiograms, pacemaker interrogations, and 24 h Holter monitors between 5 months and 2 years following pacemaker implantation. The results of these examinations were evaluated for upper rate behavior and used for programming optimization.

Results

A total of six dogs with dual-chamber pacemakers and documented upper rate behavior were included in this study (Table 1). Pacemaker settings for these dogs are outlined in Table 2.

Among the six dogs, three dogs had a transvenous single pass, passive lead system with floating atrial electrode implanted and were programmed in VDD, one dog had a transvenous dual passive lead system implanted and programmed in DDD, one dog had an epicardial dual lead system implanted and programmed in VDD, and one dog had an epicardial dual lead system implanted and programmed in DDD [8]. Four dogs had a Medtronic pacemaker system[c] implanted, and two dogs had a

[c] Medtronic, Inc, Minneapolis, MN.

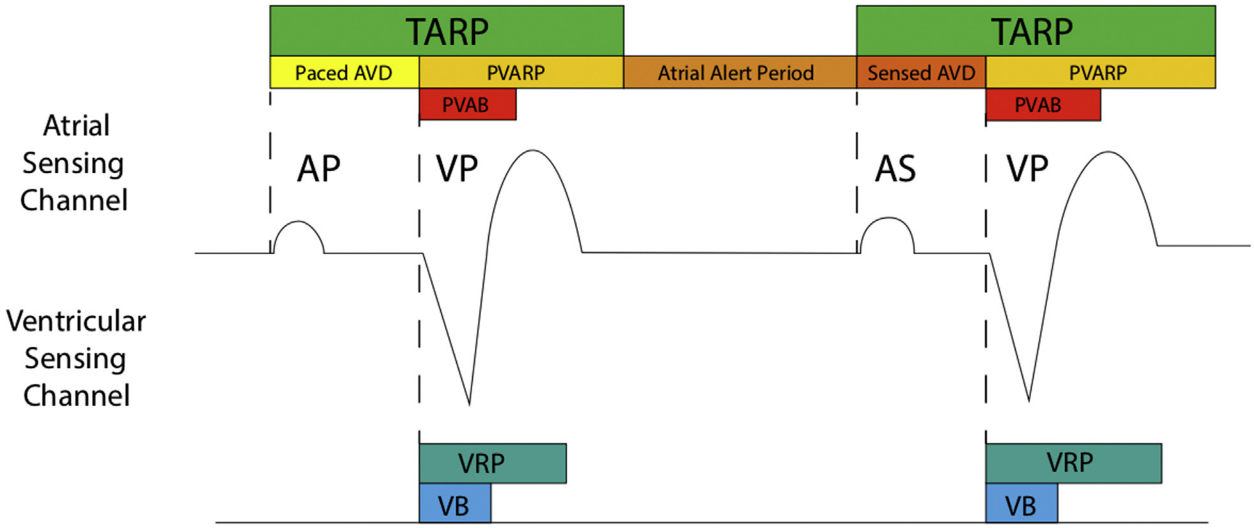

Fig. 1 Timing intervals in the DDD pacing mode—A surface ECG is shown with atrial and ventricular event markers. There is both an atrial sensed and atrial paced event that are both followed by a ventricular paced event. Timing intervals pertaining to the atrium, atrioventricular node, and ventricle are also shown. The atrioventricular delay will differ between paced and sensed atrial events. AP, atrial paced; AS, atrial sensed; AVD, atrioventricular delay; ECG, electrocardiography; PVAB, postventricular atrial blanking period; PVARP, postventricular atrial refractory period; TARP, total atrial refractory period; VB, ventricular blanking; VP, ventricular paced; VRP, ventricular refractory period.

Table 1 Age at implantation, breed, sex, rhythm diagnosis, pacemaker manufacturer, lead type and implantation method, and pacing mode of dogs with dual-chamber pacemakers showing upper rate behavior.

Dog	Age (years)	Breed, Sex	Diagnosis	Pacemaker manufacturer	Lead	Implantation	Pacing mode
1	7	CKCS, FS	3rd AVB	Medtronic, Adapta ADDRL1	Dual	Epicardial	VDD
2	3	Mixed breed, MC	3rd AVB	St. Jude Medical, Verity ADx XL DR5356	Single	Transvenous, passive	VDD
3	4	Mixed breed, FS	3rd AVB/ATA	St. Jude Medical, Accent DR2110	Single	Transvenous, passive	VDD
4	5	Mixed breed, FS	3rd AVB/ATA	Medtronic, Adapta ADDR03	Dual	Transvenous, passive	DDD
5	2	GSD, MI	3rd AVB	Medtronic, Adapta ADDRL1	Single	Transvenous, passive	VDD
6	1	Cane Corso, FI	3rd AVB	Medtronic, Versa VEDR01	Dual	Epicardial	DDD

ATA, atrial tachyarrhythmia; CKCS, Cavalier King Charles Spaniel; GSD, German Shepherd Dog; FI, female intact; FS, female spayed; MC, male castrated; MI, male intact; 3rd AVB, third degree atrioventricular block.

St. Jude pacemaker system implanted[d] (Table 1). The underlying rhythm diagnosis warranting pacemaker implantation was third degree AV block in all dogs (Table 1). Dog #6 developed third degree AV block during definitive surgical repair of Tetralogy of Fallot under cardiopulmonary bypass. The repair included a patch graft of a large ventricular septal defect, which damaged the AV node. The etiology of third degree AV block in the remaining dogs was suspected to be secondary to AV node degeneration or other undetermined etiology. Concurrent ATA was documented in two dogs (dogs # 3 and 4). Clinicians elected to implant dual chamber pacemaker systems due to the young age of the dogs with the intent to limit long-term consequences of AV dyssynchrony [4]. There were no major complications described during pacemaker implantation. Minor complications included postoperative ventricular ectopy, treated with sotalol in one dog (dog #5) that was successfully tapered and discontinued 2 months after

[d] St. Jude Inc, St. Paul, MN.

Table 2 Initial and optimized parameters for dogs with dual-chamber pacemakers with upper rate behavior.

Dog	1 (initial)	1 (optimized)	2 (initial)	2 (optimized)	3 (initial)	3 (optimized)	4 (initial)	4 (optimized)	5 (initial)	5 (optimized)	6 (initial)	6 (optimized)
Lower rate limit (bpm)	100	**70**	60	60	65	65	60	60	40	40	100	**60**
Upper rate limit (bpm)	180	**170**	140	**160**	170	**180**	150	150	200	200	180	180
Sensed AV Delay (msec) with maximum offset (msec)	90 (−40)	90 (−40)	140 (−50)	140 (−50)	120 (−30)	**120 (−20)**	120	120	120 (−20)	**120 (−30)**	120 (−40)	**130 (−50)**
PVARP (msec)	180	180	225	225	175	175	320	**200**	250	**180**	180	**160**
TARP (msec)	230	230	315	315	265	**275**	440	**320**	350	**270**	260	**240**
2:1 Block point (bpm)	261	261	190	190	226	**218**	136	**188**	171	**222**	231	**250**
Pacemaker Wenckebach window (bpm)	180–261	**170–261**	140–190	**160–190**	170–226	**180–218**	URL > 2:1 block point	**150–188**	URL > 2:1 block point	**200–222**	180–231	**180–250**

The bolded values indicate values that were changed between the initial and optimized settings for each dog.
AV delay with programmed maximum offset in parentheses; AV, atrioventricular; bpm, beats per minute; PVARP, postventricular atrial refractory period; TARP, total atrial refractory period; URL, upper rate limit.

initiation. The median age at pacemaker implantation was 3.5 years (range 1–7 years). Two of the six dogs had evidence of concurrent degenerative mitral valve disease at the time of pacemaker implantation (dogs #1 and #4).

Pacemaker Wenckebach and 2:1 AV block were noted in four of the dogs with dual-chamber pacemakers at higher heart rates (dogs #1, #2, #5, and #6). Figure 2 demonstrates the interrogation strip along with surface electrocardiogram during pacemaker Wenckebach from dog #1. Figure 3 demonstrates the interrogation strip from dog #6 and surface electrocardiography (ECG) from dog #1 during 2:1 AV block. Automatic mode switch was documented in two dogs (dogs #3 and #4) in association with an ATA (Fig. 4). Overdrive pacing was attempted in one of these dogs (dog #4) but failed to convert the ATA (Fig. I, figure available in Supplemental Data on-line). Blanked flutter search was documented in one dog (dog #6) (Fig. II, figure available in Supplemental Data on-line).

Twenty four hour Holter monitors were recorded from two of the dogs (dogs #2 and #5) between 2 months and 2 years after pacemaker implantation. Both were active, athletic dogs, and the programmed settings allowed 1:1 tracking up to the programmed upper rate limit (URL) and a pacemaker Wenckebach window up to the 2:1 block point, although neither dog reached this block point. Both dogs were asymptomatic according to the owners with adequate perceived exercise tolerance. In all dogs, upper rate behavior was initially observed during pacemaker interrogation in the clinic associated with periods of physiologic sinus tachycardia or ATA (dog #3 and #4). The pacemaker programming parameters at which the upper rate behavior was noted as well as adjusted parameters to limit this behavior are recorded in Table 2. All dogs were perceived to be without clinical signs during upper rate behavior. At the time of publication, four of six dogs were alive (dogs # 2, #3, #5, and #6), and median time from pacemaker implantation was 1023 days (range of 76–1393 days). Dog #1 was euthanized due to refractory congestive heart failure from advanced degenerative mitral valve disease 1323 days after pacemaker implantation. Dog #4 was deceased 1094 days after pacemaker implantation secondary to right-sided congestive heart failure and pacemaker-lead thrombosis. The cause of right-sided congestive heart failure in this dog was believed to be secondary to both impaired venous return from thrombus formation around the lead as well as to right ventricular dysfunction. The dog's concurrent ATA prevented AV synchrony during

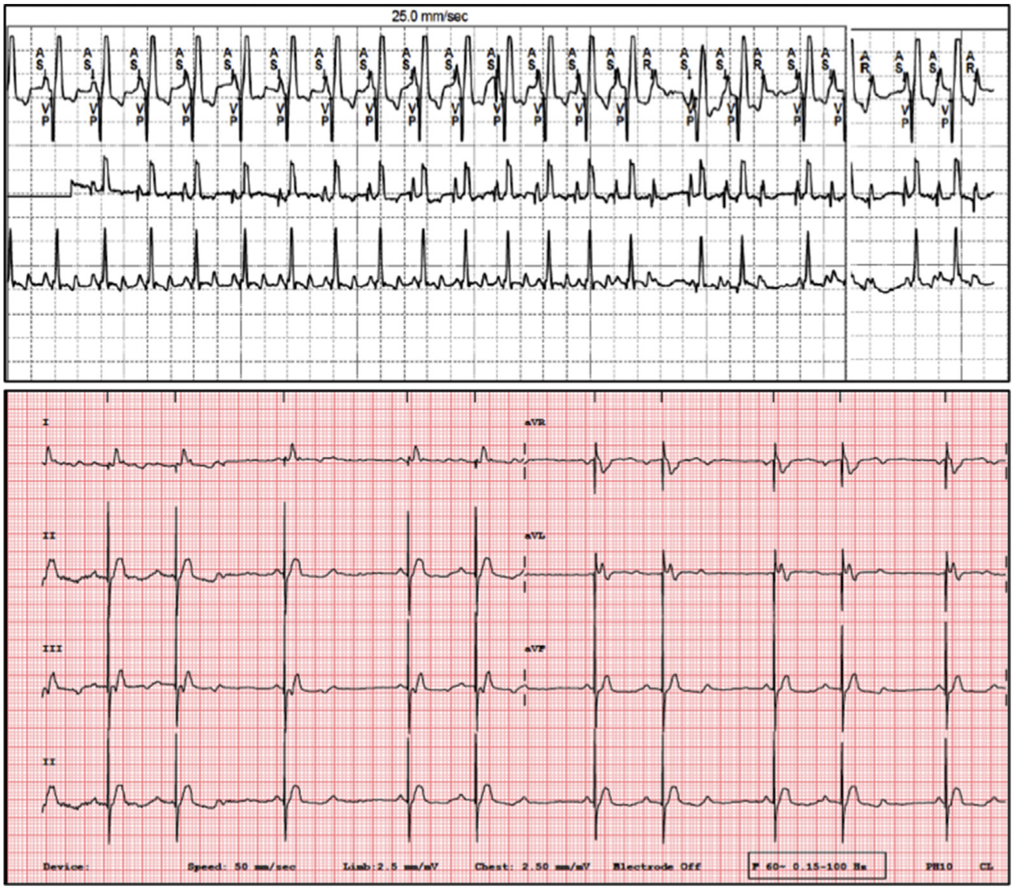

Fig. 2 **Pacemaker Wenckebach**—Pacemaker interrogation strip along with 6-lead surface ECG of dog #1 demonstrating pacemaker Wenckebach at heart rates >170 beats per minute. The interrogation strip includes lead II (top line), atrial electrogram (middle), and lead I (bottom). ECG, electrocardiography.

pacing even though a dual-chamber system was implanted as most of the time the dog was paced in a DDIR mode (dual chamber pacing and sensing, but inhibited mode only with rate modulation) to avoid rapid ventricular response to the ATA. This lack of AV synchrony and chronic ATA are believed to have precipitated right ventricular dysfunction which, in combination with thrombosis around the lead, eventually manifested as congestive heart failure.

Discussion

Upper rate behavior was observed in six dogs with dual-chamber pacemakers and complete AV block. Pacing parameters were altered to extend the pacemaker Wenckebach period and limit risk for development of 2:1 AV block as well as to limit deleterious effects of mode switching.

When a dual-chamber pacemaker is programmed in a tracking mode with or without rate modulation (DDD, DDDR, VDD, VDDR), upper rate behavior can be noted in response to increasing atrial rates and may result in a sudden or problematic alteration of ventricular rate. Upper rate behaviors are most often initiated by exercise, stress, sinus tachycardia, or ATA. In human medicine, upper rate behaviors are well documented, and certain programming strategies are implemented to limit the potentially detrimental behavior of pacemaker tracking [15]. This may be more apparent in patients who rely on the pacemaker for AV synchrony, as was the case in our study population of dogs with complete AV block.

To understand upper rate behavior, it is essential to understand the timing intervals of dual-chamber pacing (Fig. 1). There are three main timing cycles for the atrial channel (atrial alert period, AV delay [AVD], and postventricular atrial refractory period [PVARP]) and three main timing cycles for the ventricular channel (ventricular alert period, ventricular blanking period, and ventricular refractory period) [16]. Timing cycles allow AV synchrony by coordinating atrial activity with ventricular activity, prevent pacemaker

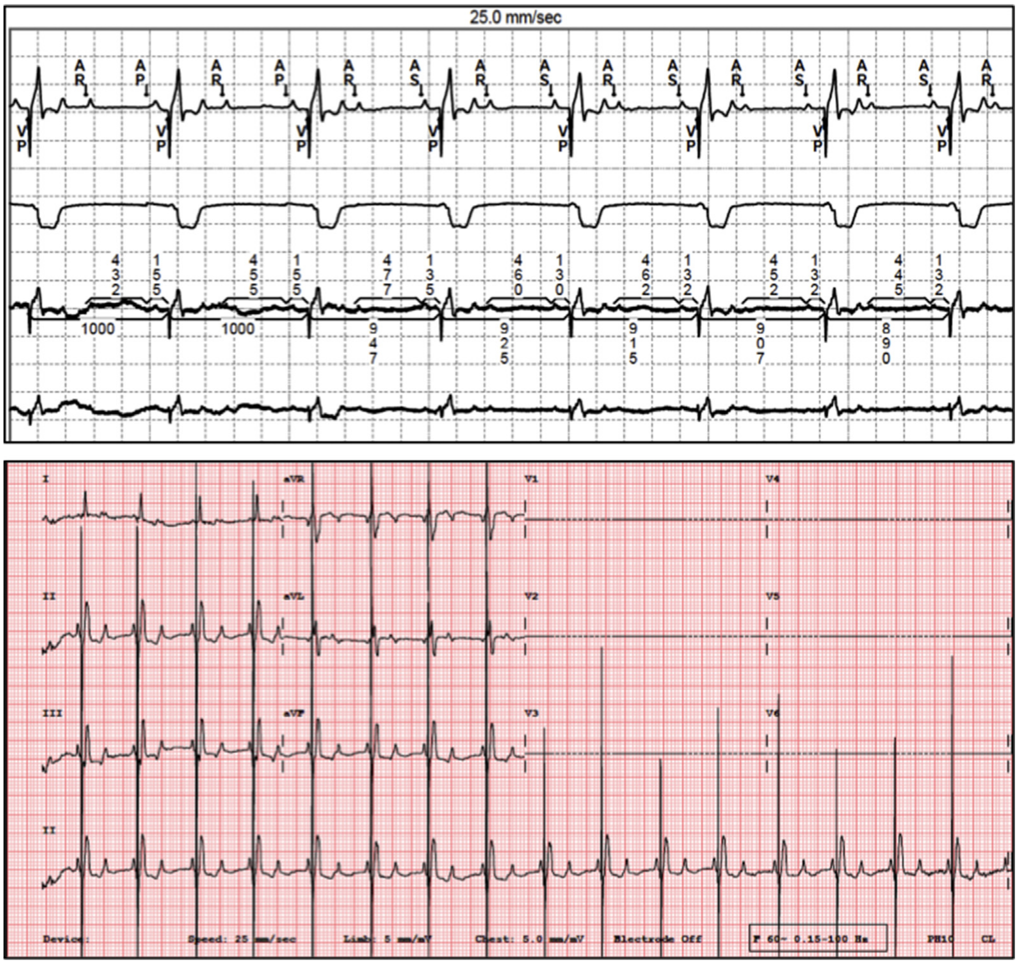

Fig. 3 2:1 atrioventricular block—Pacemaker interrogation strip from dog #6, which includes lead II (top line) with pacemaker marker channel, ventricular electrogram (2nd line), lead III with measured cycle lengths (3rd line), and lead I (bottom line), along with a 6-lead surface ECG from dog #1. Both examples demonstrate 2:1 AV block at rates above the programmed 2:1 block point. For dog #6, the 2:1 block point was programmed to be 120 beats per minute, and the current atrial rate is 136 beats per minute. These settings were in the postoperative period prior to final programming for discharge. For dog #1, the 2:1 block point was programmed to be 180 beats per minute and current atrial rate is 188 beats per minute. ECG, electrocardiography.

mediated tachycardias, and allow a more physiologic response to fast atrial rates. The timing intervals determine when paced events occur in a given pacing mode. Timing intervals are initiated by intrinsic cardiac events or delivery of a pacing output and will continue until programmed completion or termination by sensed cardiac events [15]. The lower rate interval is the interval between a ventricular event and the next paced ventricular event and will therefore determine the lower rate limit [15,17]. The AVD is the interval between an atrial event and the next scheduled ventricular paced event and is further qualified by the terms sensed and paced depending on the origin of the atrial event. A ventricular pacing stimulus is delivered at the end of the AVD if an intrinsic ventricular depolarization does not occur during this time. The AVD is designed to mimic the native PR interval and is programmed to maintain AV synchrony [18]. The interval between a ventricular event and the next scheduled atrial paced event is the atrial escape interval (also referred to as ventriculoatrial interval). Rate-adaptive AVD is a parameter that is programmable and allows the AVD to shorten with increasing heart rates to mimic the physiologic shortening of the PR interval. This allows optimization of AV synchrony at upper tracking rates. Both a sensed and paced AVD can be programmed. With programmable rate-adaptive AVD, a maximum offset can be programmed which will result in a minimum AVD. This will affect the TARP, which is important during programming to avoid undesirable upper rate behavior [15].

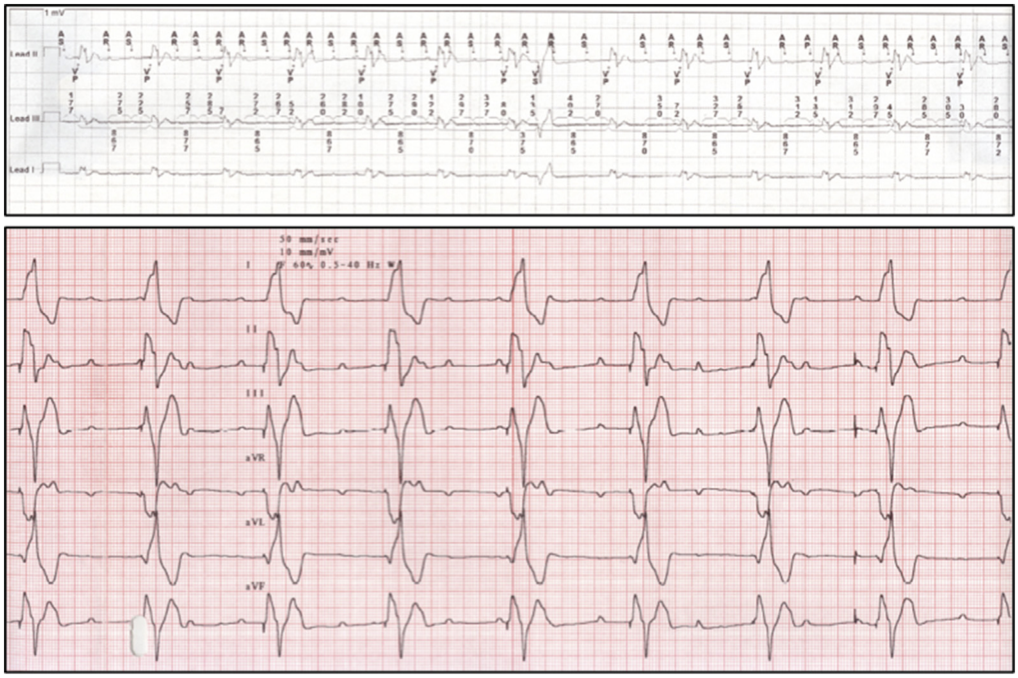

Fig. 4 **Automatic mode switch**—Surface ECG and interrogation strip from dog #4 after automatic mode switch due to a sensed atrial rate >185 beats per minute (automatic mode switch detection rate programmed at 185 beats per minute). The pacemaker then mode switched from DDD to DDIR and in the example is rate-responsive pacing at a ventricular rate of approximately 70—80 beats per minute. Interrogation strip paper speed is 25 mm/s with a sensitivity of 5 mm/mV. ECG, electrocardiography.

In dual-chamber sensing, there are refractory periods following atrial and ventricular events. The ventricular refractory period is initiated by a ventricular event. The atrial refractory period is initiated by an atrial event and includes the AVD and PVARP [15]. The PVARP is designed to prevent sensing far-field R waves or retrograde P waves. Therefore, the TARP is the sum of AVD and PVARP. The first portion of each refractory period is termed the blanking period and is equivalent to the absolute refractory period of the heart. The pacemaker is blind to any events that occur during this period. The first portion of PVARP is therefore the postventricular atrial blanking period. The second portion of the refractory period is equivalent to the relative refractory period and intrinsic events occurring during this period will be sensed. These sensed events in the refractory period are utilized for other device functions such as detection for response to ATA and non-physiologic signals. There is also an upper rate interval (URI) that determines the maximum paced ventricular rate in response to sensed atrial activity and will set the URL or maximum tracking rate [15,17].

In dual-chamber tracking modes, 1:1 tracking of intrinsic atrial activity is desirable but tracking of ATA may result in unfavorable hemodynamic effects. To limit the fastest atrial rate that can be tracked 1:1, the URL can be adjusted. The TARP sets an upper limit of 1:1 tracking though this upper limit can be reached prior to the URL depending on device programming. Upper rate behavior is apparent when the intrinsic atrial activity is faster than the programmed URI [15].

Pacemaker Wenckebach upper rate response

When atrial tracking rates are faster than the URL, the ventricular paced beats are delayed (AVD is prolonged) so that the ventricular rate never exceeds the URL. As the AVD is prolonged, each successive atrial sensed event occurs closer to the preceding ventricular paced beat, until the atrial event falls into PVARP and is not tracked. The subsequent atrial activity is tracked without AVD prolongation and the process repeats. The maximum prolongation of the AVD is the difference between the URI and TARP [15]. To avoid pacemaker Wenckebach during exercise, the URL should ideally be programmed high enough to allow 1:1 tracking through maximum physiologic atrial rates.

2:1 Block point

As the intrinsic atrial rate continues to increase, the atrial rate interval eventually becomes shorter than the TARP and every other P wave will fall within PVARP and not be tracked. This leads to 2:1 tracking and effectively results in 2:1 AV block (Fig. 3). Block of 2:1 is most common but at higher atrial rates, higher forms of fixed ratio block (3:1, 4:1) can occur. As TARP (AVD plus PVARP) is increased, the 2:1 block point will be reduced. The 2:1 block point is calculated as 60,000 divided by TARP in msec. If the URL is programmed higher than the 2:1 block point, the patient's ventricular rate will abruptly drop to half of the atrial rate when the 2:1 block point is exceeded [15].

Programming to avoid abrupt 2:1 AV block

Undesirable upper rate behavior is avoided by permitting a zone of pacemaker Wenckebach before development of 2:1 tracking (Fig. 2). The pacemaker Wenckebach window is created between the URI and TARP, while at the same time programming the URL high enough to allow 1:1 tracking through maximum physiologic atrial rates. Similarly, it is important to program a high enough 2:1 tracking rate (short enough TARP) to avoid 2:1 AV block at physiologic atrial rates [15]. For example, to allow a pacemaker Wenckebach window between 180 beats per minute and 222 beats per minute, the URL should be programmed at 180 beats per minute and the 2:1 AV block point should be programmed at 222 beats per minute (TARP 270 msec, AVD 90 msec, PVARP 180 msec; TARP (msec) = [AVD (msec) + PVARP (msec)]; TARP = [(60,000 ms/min)/222 beats per minute]; 2:1 block point (beats per minute) = [(60,000 ms/min)/TARP (msec)]) (Table 2). With these settings, the patient will experience 1:1 tracking up to a heart rate of 180 beats per minute, then display pacemaker Wenckebach from 180 beats per minute to 222 beats per minute, prior to switching to 2:1 AV block at rates >222 beats per minute (Fig. 5). Special consideration should be made by the clinician in regard to maximum physiologic atrial rates in younger and athletic dogs. With this consideration, a specific pacemaker Wenckebach window can be identified prior to a 2:1 block point for the patient to avoid a drastic drop in ventricular tracking rates at physiologic atrial rates.

Automatic mode switching

When ATA occur, atrial tracking modes can result in rapid ventricular pacing with resultant hemodynamic compromise. Current devices have algorithms that detect the presence of ATA and automatically switch to a non-tracking mode (VVI, DVI, or DDI, with or without rate response) [19].

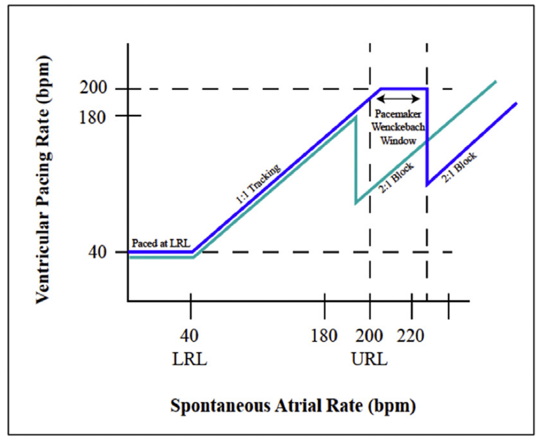

Fig. 5 Relationship between Pacemaker Wenckebach and 2:1 atrioventricular block—The spontaneous atrial rate is shown on the x-axis with ventricular pacing rate on the y-axis. As the patient's atrial rate increases from the lower rate limit toward the upper rate limit, the atrial rate and ventricular pacing rate will track 1:1. Example #1 (teal line): if the upper rate interval (URI) is less than total atrial refractory period (TARP) (2:1 block point is less than the upper rate limit [URL]), then the patient will abruptly 2:1 AV block prior to reaching the URL. Lower rate limit (LRL) = 40 beats per minute, upper rate limit (URL) = 200 beats per minute, TARP = 315 msec, 2:1 block point = 190 beats per minute. Example #2 (royal blue line): Alternatively, if the URI is greater than TARP (2:1 block point is greater than the URL), then the patient will advance through a pacemaker Wenckebach window at which time the ventricular pacing rate will not exceed the URL, and the Wenckebach ratio will progressively increase as the atrial rate increases until the 2:1 block point is reached (see text for additional details). LRL = 40 beats per minute, URL = 200 beats per minute, TARP = 270 msec, 2:1 block point = 222 beats per minute.

Mode switching allows for monitoring of the atrial rhythm, without fear of conducting the tachycardia. Atrial events are sensed in the alert period as well as during the unblanked portion of PVARP. These time periods are utilized for ATA detection. Mode-switching functions are often programmable, and there is a specific atrial rate threshold which defines the ATA detection rate. Many algorithms have been developed that vary in sensitivity and specificity of detection of ATA [20]. Following a mode-switch event, atrial activity is scanned so that a tracking mode resumes upon arrhythmia termination [20]. Clinical studies have shown that the incidence of ATA and mode switching algorithms in human patients with dual-chamber pacemakers is high (50–60%) [20].

A sudden change to a lower ventricular pacing rate when AMS occurs may result in clinical signs. This is prevented by several mechanisms—permitting mode switch to a rate-adaptive pacing mode, even if the sensor is disabled in the tracking mode [15]. A randomized, double-blind crossover study in humans compared DDDR with mode switching or DDDR with conventional upper rate behavior to VVIR pacing [21]. Overall, DDDR with mode switching was superior to VVIR by both objective measure (exercise time) and subjective assessment (perceived well-being) [21]. This supports the use of the AMS modality; however, given higher heart rates in dogs, care must be taken to program the AMS appropriately. One method that the authors have used in the clinical setting is to set the AMS detection rate to be at the upper end of the pacemaker Wenckebach window prior to the 2:1 block point to have the patient mode switch to the lower rate limit (with rate response capability) prior to abruptly experiencing 2:1 AV block. An additional consideration for programming AMS is in the immediate postoperative period, such as in a postsurgical patient that will have limited activity. In this situation, as was the case for one of the dogs included in this series (dog #6), AMS was turned off in the postoperative period. In a laterally recumbent patient during the postoperative period with no sensed movement, a sinus tachycardia that reached the AMS detection rate would result in mode switch and an abrupt decrease in the paced rate to the lower rate limit which may be hemodynamically undesirable. Therefore, consideration should be made for the hemodynamic effects of AMS in a patient with limited mobility but increased sympathetic drive as in the postoperative period.

An additional feature that can be utilized when AMS is enabled is blanked flutter search in Medtronic devices. This is an algorithm that was designed to protect a patient from tracking at upper rates in cases of atrial flutter, in the case that alternate atrial signals fall within the postventricular atrial blanking period resulting in 2:1 tracking of atrial flutter. Medtronic devices have a blanked flutter search algorithm that is activated when the atrial sensed interval is less than AVD plus postventricular atrial blanking period for eight consecutive cycles. The device will then extend PVARP for one cycle, allowing another atrial sensed signal to be sensed, and if the atrial rate is sensed at less than the ATA detection interval, a diagnosis of atrial flutter is made and the device mode switches [15]. Figure II (figure available in Supplemental Material on-line) shows an example of blanked flutter search in dog #6 documented while the AMS feature was turned on. An additional helpful feature of AMS is that mode switching events can be reliable surrogate markers for frequency of ATAs [22]. By utilizing the AMS feature in canine dual-chamber pacing, rapid ventricular pacing can be avoided.

Overdrive pacing

There are various pacing algorithms for ATA prevention that have been developed targeting specific situations. The most commonly used antitachycardia pacing mode is overdrive pacing. The atria are paced at a rate faster than the tachycardia rate with the goal of capturing the atria and restoring a sinus rhythm. The cycle length for tachycardia termination is at times 15—30% shorter than the tachycardia cycle length [23]. The most commonly used modes are burst pacing and ramp pacing. In burst pacing, the cycle lengths within the burst are the same. In ramp pacing, the pacing rate during the same sequence of overdrive pacing increases successively [23]. Human studies have demonstrated the safety of automatic atrial overdrive pacing for prevention and termination of ATA with a dual-chamber pacemaker. Atrial antitachycardia pacing terminated 53% of treated ATA episodes without any proarrhythmic effects in one study [24]. In dog #4, overdrive pacing was performed due to persistent ATA that was unresponsive to antiarrhythmic therapy. Burst pacing was performed at cycle lengths at between 195 and 250 msec for 5—15 s in duration (Fig. I, figure available in Supplemental Material on-line). Four bursts were performed and were unfortunately unsuccessful at terminating the ATA. Although this method was not successful in the dog described, this strategy may be utilized in the clinical setting for persistent ATA when a dual-chamber pacemaker has been implanted.

Conclusion

In human medicine, dual-chamber pacemakers are used to maintain AV synchrony, and this is also feasible in canine patients. This article demonstrates that upper rate behavior is observed in canine patients, and care should be taken when considering timing intervals and upper tracking rates. By optimizing programmed timing intervals, patients may experience more physiologic upper rate behavior, and this may be increasingly important in an active, athletic patient. When managing a patient with ATA, both AMS and overdrive pacing can be considered. Although at this time, it is unknown whether detrimental upper rate behavior leads to patient discomfort or results in a decreased exercise ability, detailed programming of dual-chamber pacemakers should be a priority in management of canine patients.

Conflicts of Interest Statement

One author (A.M.T.) is employed by Medtronic, and the other authors do not have any conflicts of interest to disclose.

Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jvc.2018.11.005.

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