Bipolar atrial sensing thresholds in sinus rhythm and atrial tachyarrhythmias

A comparative analysis in patients with DDDR pacemakers


Department of Cardiology, Kerckhoff Clinic, Bad Nauheim, Germany

Automatic mode switching (AMS) function in dual chamber pacemakers depends on adequate detection of atrial tachyarrhythmias. There are few data on showing how intra-operative atrial signal amplitude during sinus rhythm can predict atrial tachyarrhythmias after pacemaker implantation. In 43 patients undergoing DDDR pacemaker implantation and atrioventricular nodal ablation for the treatment of drug-refractory paroxysmal atrial fibrillation, atrial sensing thresholds during sinus rhythm and during induced atrial tachyarrhythmias (24-48 h after device implantation) were analysed. Five different DDDR pacemaker systems were implanted (Chorus 7034\textsuperscript{\textregistered}, Ela Medical n=13; Meta DDDR 1254\textsuperscript{\textregistered}, Teletronics Pacing Systems n=12; Vigor DR 1230\textsuperscript{\textregistered}, Guidant n=6; Trilogy DR 2364\textsuperscript{\textregistered}, Pacesetter, n=2; Kappa DR 401\textsuperscript{\textregistered}, Medtronic USA n=10). Every patient received a steroid-eluting, screw-in, bipolar atrial lead (Medtronic, Capsure-Fix 4068\textsuperscript{\textregistered}). The mean P wave amplitude during implantation was 3.91±1.14 mV. The mean atrial sensing threshold during sinus rhythm and during all modes of induced atrial tachyarrhythmias was 3.35±1.0 mV, and 1.52±0.92 mV, respectively (P<0.001). Atrial fibrillation was induced in 36 patients. The mean sensing threshold during sinus rhythm in this patient group was 3.39±1.01 mV, the mean sensing threshold during atrial fibrillation was 1.27±0.56 mV, reflecting a 63% reduction of sensing threshold compared with sinus rhythm (P<0.001). Atrial flutter was induced in seven patients. The mean sensing threshold during sinus rhythm was 2.92±1.19 mV, the mean sensing threshold during atrial flutter was 2.79±1.26 mV, reflecting a reduction of 5% (ns) compared with sinus rhythm. Atrial sensing thresholds during sinus rhythm were significantly correlated with sensing thresholds during atrial tachyarrhythmias (r=0.44; P<0.002), but there were significant variations in intra-individual results. The reduction of atrial sensing thresholds between sinus rhythm and induced atrial tachyarrhythmias ranged from 30% to 82%.

**Conclusion:** Bipolar atrial sensing thresholds during sinus rhythm are correlated with sensing thresholds during atrial tachyarrhythmias, but there is a large degree of variance in individual patients. A 4:1 to 5:1 atrial sensing safety margin based on sensing threshold during sinus rhythm is a predictor for adequate postoperative detection of atrial tachyarrhythmias and the function of AMS devices. (Europace 1999; 1: 135–139)

**Key words:** Bipolar atrial sensing thresholds, automatic mode switch, atrial tachyarrhythmias, dual chamber pacing.

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**Introduction**

Years ago, the indication for atrioventricular (AV) sequential pacemaker (DDDR) therapy in patients with paroxysmal atrial tachyarrhythmias was limited by the fact that former pacemaker technology did not provide adequate prevention of high rate, atrial triggered, ventricular pacing during episodes of atrial tachyarrhythmias. Atrial tachyarrhythmias, predominantly atrial fibrillation, was the main cause for terminating the DDD(R) pacing mode in AV sequential pacemaker therapy\cite{1,2}. Newer technical options, such as automatic changes from an atrial triggered into an atrial inhibited pacing mode during atrial tachyarrhythmias\cite{3,4} has widely expanded the indication for DDD(R) pacemaker therapy in patients with paroxysmal atrial tachyarrhythmias\cite{5–7}. The main problem regarding the clinical performance of automatic mode switch (AMS) options is the adequate sensing of atrial endocardial signals during sinus rhythm as well as during atrial...
tachyarrhythmias, especially during atrial fibrillation. Limited data exist regarding the relationship of the endocardial signal amplitudes between sinus rhythm and atrial tachyarrhythmias in patients with AV sequential pacemaker therapy[6,9]. This study was conducted to evaluate the relationship between endocardial sensing thresholds during sinus rhythm and during atrial tachyarrhythmias in patients undergoing DDDR pacemaker therapy and AV nodal ablation due to drug-refractory paroxysmal atrial tachyarrhythmias. The aim of the study was to establish recommendations for the programming of atrial sensing safety margins based on the sensing threshold during sinus rhythm to achieve adequate sensing of atrial tachyarrhythmias and AMS function.

**Patients and Methods**

Forty-three consecutive patients undergoing DDDR pacemaker implantation and radiofrequency (RF) AV nodal ablation were enrolled in this study. Every patient demonstrated drug-refractory paroxysmal atrial fibrillation, and all gave informed consent. Four different DDDR pacemaker systems that included an AMS feature were implanted. A bipolar, screw-in, steroid-eluting atrial lead (Capsure 4068, Medtronic) was used in every patient. The implantation of the atrial pacing lead was optimized to achieve the highest atrial signal amplitude measurements. All pacemaker implantations and postoperative sensing threshold measurements were performed during sinus rhythm. Antiarrhythmic drug treatment was stopped >5 half-lives prior to study enrollment. During pacemaker implantation, all lead-related measurements were performed in a bipolar mode using a single pacemaker analyser system. Atrial bipolar lead measurements included the determination of pacing threshold (V/0·5 ms), atrial signal amplitude (mV), determination of slew-rate (V/s) and pacing impedance (Ohm–5 V/1·0 ms). Two to 4 days after pacemaker implantation, RF ablation of the AV node was performed. Prior to AV nodal ablation, the atrial lead measurements of pacing threshold, pacing impedance and sensing threshold performed intra-operatively were repeated via device telemetry. The method of RF AV nodal ablation has been previously described[10]. After achieving a complete third-degree AV block, atrial tachyarrhythmias were induced by high rate atrial pacing via the ablation catheter. During induced atrial tachyarrhythmias, bipolar atrial sensing thresholds were determined via device telemetry. The implanted pacemakers were programmed to DDD mode, the upper tracking rate was set at 150 beats.min⁻¹. The post-ventricular atrial refractory period (PVARP) was programmed between 200–250 ms. In the case of a programmable post-ventricular atrial blanking period (PVABP) values of 120 ms were programmed. Sensed AV delays were programmed at 100 ms. Atrial sensing thresholds for induced atrial tachyarrhythmias were defined as the lowest programmable atrial sensitivity providing continuous atrial-tracked ventricular pacing at the upper tracking rate for a duration of at least 2 min.

All data are given as mean ± SD. Data analysis was performed using the Wilcoxon rank signed test and the Spearman rank correlation coefficient. The level of significance was P<0·05.

**Results**

Forty-three patients (26 male, 17 female) were enrolled in this study. Patients’ mean age was 61·0 ± 8·2 years. Sixteen patients (37-2%) were classified as patients with ‘lone atrial fibrillation’, and 27 (62-7%) patients showed structural cardiac abnormalities, with a predominance of hypertensive heart disease (19 patients). Paroxysmal atrial fibrillation had been present for a mean duration of 6·0 ± 2·7 years. The echocardiographically determined left ventricular ejection fraction was 48·9 ± 5%. Four different DDDR pacemakers were implanted: Meta DDDR 1254®, Teletronics Pacing Systems, n=12; Chorus RM 7034®, Ela Medical, n=13; Vigor DR 1230®, Guidant, n=6; Trilogy DR 2364®, Pacesetter, n=2; Kappa DR 401®, Medtronic, n=10.

**Atrial lead related measurements during implantation**

The mean atrial pacing threshold was 0·8 ± 0·2 V, and the mean pacing impedance 536·3 ± 75 Ohm. The mean atrial signal amplitude during sinus rhythm was 3·9 ± 1·1 mV, and the mean slew-rate 0·44 ± 0·14 V/s. The intra-operative measurements were completed in every patient.

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No lead dislodgment was observed. By RF ablation third-degree AV block was achieved in every patient. Via device telemetry, atrial sensing thresholds were measured during sinus rhythm. The mean sensing threshold was 3·35 ± 1·0 mV. By high rate atrial pacing, 36 patients had atrial fibrillation induced and seven patients atrial flutter. The mean sensing threshold in all induced atrial tachyarrhythmias was 1·52 ± 0·92 mV, reflecting a significant reduction of 54·9% compared to the mean sensing threshold during sinus rhythm (P<0·001). The mean sensing threshold during sinus rhythm in patients with inducible atrial fibrillation was 3·39 ± 1·01 mV. The mean sensing threshold during...
atrial fibrillation was 1.27 ± 0.56 mV, reflecting a reduction in sensing threshold of 62.5% compared with sinus rhythm \((P < 0.001)\). The results in patients with induced atrial flutter were different. The mean atrial sensing threshold during sinus rhythm in these patients was 2.92 ± 1.19 mV. The mean sensing threshold during atrial flutter was 2.79 ± 1.26 mV, reflecting a slight, non-significant reduction of 5%. The smallest reduction in sensing threshold between sinus rhythm and atrial fibrillation was 30% (sensing in sinus rhythm: 4 mV vs sensing in atrial fibrillation 2.8 mV), the largest reductions were 82%, observed in two patients. A reduction of sensing thresholds in the range between 25%–50% occurred in 9/36 patients (25%). In these patients, the mean sensing threshold during sinus rhythm and atrial fibrillation was 3.01 ± 1.1 mV and 1.81 ± 0.7 mV, respectively. In 25/36 patients (69%) a reduction in the range between 51%–75% was observed. In these patients, the mean sensing threshold in sinus rhythm and atrial fibrillation was 3.49 ± 1.0 mV and 1.13 ± 0.4 mV, respectively. A reduction of greater than 75% was observed in two patients (6%). In both patients, the sensing threshold in sinus rhythm was 4.0 mV, but this declined to 0.7 mV in atrial fibrillation. There was a significant correlation between sensing thresholds during sinus rhythm and during all induced atrial tachyarrhythmias \((r = 0.44; P < 0.002)\), as well as between sinus rhythm and atrial fibrillation \((r = 0.5; P < 0.002)\) (Figs 1 and 2). A further subanalysis revealed that the decrease in atrial sensing threshold was neither related to patients’ clinical data nor, to sinus rhythm sensing thresholds, nor to the type of implanted pacemaker.

**Discussion**

This study has three major results, (1) there is a significant, but weak correlation between atrial sensing thresholds during sinus rhythm and atrial fibrillation (2) atrial sensing thresholds in sinus rhythm and in atrial flutter show no significant difference (3) there is a clinically significant, non-predictable degree of patients’ individual reduction in atrial sensing thresholds between sinus rhythm and atrial fibrillation, ranging from 30% to 82%.

Atrial endocardial signal amplitudes during atrial tachyarrhythmias had been reported to be lower than signal amplitudes in sinus rhythm\(^{[11]}\). A low level of clinical data has been reported with regard to the atrial signal amplitude or sensing threshold during sinus rhythm which will predict adequate sensing of atrial tachyarrhythmias in patients undergoing DDD(R) pacemaker implantation with documented paroxysmal atrial tachyarrhythmia. The implantation of the atrial pacing leads in our study was primarily guided by the highest achievable atrial signal amplitude measurement during sinus rhythm. The atrial sensing thresholds in the present study population were optimized. The variation in signal amplitude in consecutive atrial depolarizations during atrial fibrillation is well known\(^{[11]}\), and may cause inadequate behaviour of AMS during atrial fibrillation in some patients. Therefore, the atrial sensing thresholds during atrial fibrillation, determined via pacemaker telemetry, were not defined by the atrial sensitivity at the first occurrence of AMS function. This definition of an atrial sensing threshold would not adequately detect
atrial tachyarrhythmia over a prolonged period of atrial fibrillation. The determination of atrial sensing thresholds during atrial fibrillation, used in our study, should provide results with a high specificity, and be unaffected by differences in the implemented AMS algorithms in the implanted devices\cite{12}. The study results demonstrate that there is considerable unpredictable variance in the reduction of atrial sensing thresholds between sinus rhythm and atrial fibrillation. The reduction in sensing thresholds ranged from 30% to 82%, but no patient showed a reduction less than 30%. The majority of patients (69%) demonstrated a reduction in sensing thresholds in the range of 51% to 75%. Inspection of our data shows that the reduction in sensing thresholds was neither related to patients’ clinical data, nor to the baseline sensing threshold during sinus rhythm, nor to the type of implanted pacemaker. Therefore, the magnitude of the reduction in sensing thresholds between sinus rhythm and atrial fibrillation is not predictable prior to or during pacemaker implantation. These results indicate that during pacemaker implantation in patients with documented paroxysmal atrial fibrillation, a potential reduction in sensing threshold up to 80% of the baseline sensing threshold during sinus rhythm should be taken into consideration.

In patients with induced atrial flutter, there was no significant reduction in atrial sensing thresholds compared with sinus rhythm. Therefore, atrial sinus rhythm sensing thresholds could predict adequate sensing of atrial flutter in patients undergoing DDD pacemaker implantation. As patients with clinically documented atrial flutter are at high risk for the development of atrial fibrillation\cite{13}, it is recommended that atrial sensing safety margins be implemented during pacemaker implantation comparable to that in patients with documented atrial fibrillation.

Previous studies

Palma and co-workers\cite{8} investigated atrial sensing thresholds during sinus rhythm and atrial tachyarrhythmias in 18 patients with implanted DDDR pacemakers. In 14 patients with atrial fibrillation, they found a 30% reduction (2.06 mV, vs 1.46 mV; \( P > 0.05 \)) of mean sensing thresholds during sinus rhythm compared with atrial sensitivities providing adequate AMS function during atrial fibrillation. The smaller reduction in the mean sensing threshold compared with our study could be explained by the fact that in Palma’s study\cite{8} four of 14 patients with atrial fibrillation showed no change, or even an increase in sensing thresholds compared with sinus rhythm. Consistent with other authors\cite{11} we did not observe this result in any of our patients. In comparison with our study, Palma and co-workers\cite{8} found a large variety in individual results regarding reduction of sensing thresholds during atrial fibrillation. The maximum reduction in sensing thresholds between sinus rhythm and atrial fibrillation was 89.9%. With a programmed 3:1 atrial sensing safety margin, based on thresholds obtained during sinus rhythm, 6/14 patients (43%) showed no adequate AMS function. Wood and co-workers\cite{11} did a comparative analysis of atrial endocardial signal amplitudes between sinus rhythm and atrial fibrillation and atrial flutter in 25 and 44 patients, respectively. This investigation was performed using diagnostic electrophysiological catheters and not implanted pacemaker leads. These investigators found a
significant correlation between signal amplitudes in sinus rhythm, and atrial fibrillation/atrial flutter (r=0.79; r=0.94; both P<0.0001). The mean atrial amplitudes were 1.59 ± 1.36 mV during sinus rhythm and 0.77 ± 0.58 mV in atrial fibrillation (P<0.0001), reflecting a mean reduction of 52%. Comparable to our study, there was a significant coefficient of variance of individual electrogram amplitudes in atrial fibrillation. Thirty-five percent of their atrial fibrillation patients with an atrial signal amplitude during sinus rhythm ≥1.5 mV showed 20% of atrial signal amplitudes during atrial fibrillation <0.3 mV. In comparison with our results, Wood and co-workers found a small 17% reduction in sensing amplitudes between sinus rhythm and atrial flutter (1.81 ± 2.07 vs 1.5 ± 1.81 mV; P<0.0001). Ricci and coworkers analysed sensing thresholds during sinus rhythm and atrial fibrillation in nine patients with implanted DDDR pacemakers. They found a strong correlation between sensing thresholds during sinus rhythm and spontaneous atrial fibrillation (r=0.85; P<0.005). Mean sensing thresholds were 3.18 ± 1.46 mV during sinus rhythm and 2.14 ± 1.04 mV during atrial fibrillation. The differences in the results between the Ricci study and ours may be explained by the small sample size in Ricci’s study and the fact that spontaneous and not induced episodes of atrial fibrillation were analysed.

**Limitations of the study**

The effect of different types of atrial pacing electrodes on changes in atrial sensing thresholds during atrial tachyarrhythmias was not evaluated. The results of our study are limited to the single type of pacing electrode used in our series. The reduction in sensing thresholds between sinus rhythm and atrial fibrillation could be underestimated due to the limitation in programming very low atrial sensitivities (>4.0 mV) in some pacemaker systems. The effects of antiarrhythmic agents were not evaluated in our study. The presented study analysed induced early onset episodes of atrial fibrillation. With respect to electrophysiological changes during prolonged episodes of atrial fibrillation, it is possible that the recommended atrial sensing safety margins would not be adequate.

**Conclusion**

There was a significant, unpredictable reduction in bipolar atrial sensing thresholds in patients with DDD pacemakers, between sinus rhythm and atrial fibrillation. The magnitude of the reduction in sensing thresholds shows great variability in the individual patient. To verify adequate atrial arrhythmia detection and AMS function a 4:1 to 5:1 atrial sensing safety margin, based on sensing thresholds during sinus rhythm, is strongly recommended.

**References**


