Limitations of the AutoCapture™ Pacing System in patients with cardiac stimulation devices

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Aims
AutoCapture (St Jude Medical) is a technological development that confirms ventricular capture analysing the evoked response after a pacing impulse and adjusts the energy output to changes in the stimulation threshold. Although this algorithm is aimed to assure capture minimizing energy consumption, some patients might not benefit from it. The objective of this study is to identify them.

Methods and results
Long-term AutoCapture efficiency was assessed using the data recorded in the programmer reports of patients undergoing scheduled pacemaker check-ups during 2012 in our institution. We have evaluated 160 consecutive patients (58% men) aged 78 ± 9 years. Pacemaker stimulation mode was DDD in 116 patients (72.5%) and VVI in 44 patients (27.5%). During the scheduled visits for pacemaker check-up, 73 patients (45.6%) showed abnormalities in the long-term AutoCapture function report (high variability in the AutoCapture stimulation threshold and/or out-of-range values). After multivariate analysis, abnormal AutoCapture pattern was associated to the presence of atrial fibrillation [odds ratio (OR) 3.96 (1.59–9.82; P = 0.05)]; and a ventricular pacing ≤25% of the time [OR 4.80 (2.09–11.05; P = 0.05)]. Auto-Capture abnormalities were also described in three (1.8%) patients with very low stimulation threshold.

Conclusion
Although AutoCapture algorithm has shown both efficacy and safety, our findings suggest that some patients with atrial fibrillation or those requiring ventricular pacing ≤25% of the time may not benefit from it. Activation of the algorithm should be individualized according to the patient’s characteristics and long-term AutoCapture pattern checked in the routine follow-up.

Keywords
AutoCapture • Pacemaker • Stimulation threshold • Cardiac devices

Introduction
Many useful technological developments have been introduced since the first pacemaker implantation in 1958.1 The AutoCapture™ Pacing System (St Jude Medical) is a proprietary algorithm designed to confirm a myocardial response (capture) analysing the evoked response (ER) after each pacemaker ventricular stimulation and to adjust the energy output of the pacing pulses in response to changes in the stimulation threshold. This algorithm sets the pacemaker output 0.25 V above the threshold measured automatically, thus increasing the longevity of the device.2,3 Although this system theoretically assures capture and decreases energy consumption, abnormal responses have been described.4 In addition, a long-term evaluation of the efficiency of AutoCapture in the real world is lacking.5,6

The correct function of the AutoCapture algorithm may vary according to certain characteristics of the paced patients, such as percentage of pacing, output threshold, underlying rhythm, etc. This prospective study is aimed at evaluating the long-term efficacy of this algorithm and identifying factors that can affect negatively the correct function of the AutoCapture system.

Methods
Patient population
Patients with St Jude Medical Accent DR and SR pacemakers equipped with the AutoCapture™ Pacing System were included in the study. In our institution, all patients in sinus rhythm receive a dual-chamber
What’s new?

- AutoCapture system is a widely used algorithm activated almost systematically in all pacemakers to reduce energy consumption. Although AutoCapture algorithm has shown both efficacy and safety, the evaluation of long-term AutoCapture data reports of 160 consecutive patients in scheduled check-ups showed some abnormalities.
- Some patients showed ‘Abnormal patterns’ with great variability in stimulation threshold and/or out-of-range stimulation threshold values.
- In these patients, an algorithm designed to reduce energy consumption might turn to waste energy.
- Atrial fibrillation and patients requiring a ventricular pacing <25% were identified as risk factors to develop these abnormalities.
- AutoCapture should not be activated systematically. It is necessary to individualize according to the patient’s characteristics.
- When activated, long-term AutoCapture pattern should be checked in the routine follow-up.

DDD pacemaker when it is indicated and only when chronic atrial fibrillation (AF) is present, a single-chamber VVI pacemaker is implanted. When a long-lasting AF is documented in a DDD pacemaker showing on permanent automatic mode switch (AMS), stimulation configuration is changed to VVI mode. It is the protocol of our Arrhythmia Unit to avoid right ventricular pacing in all the pacemakers prolonging the atrioventricular (AV) interval and using other dedicated algorithms when necessary in DDD pacemakers and programming initially backup pacing (VVI 40–50 b.p.m.) in VVI pacemakers (in patients in AF with only paroxysmal AV block/slow AF). If these VVI patients exhibit a high percentage of ventricular pacing with these settings, it could be changed to VVIR mode 50–60/100–110 b.p.m. attending to patient characteristics.

Patients were recruited in the scheduled follow-up visits during 2011. For the purpose of this investigation, the AutoCapture algorithm was systematically activated in all patients when recommended by the programmer software after performing a favourable ER test to unipolar stimulation and at least 3 months after implantation. AutoCapture ER detection system is different according to the configuration for unipolar or bipolar stimulation (DMax and PDI algorithm, respectively). St Jude Medical Accent pacemakers are provided with both algorithms. DMax was originally introduced in 1994 and detects the ER after a unipolar configuration primary pulse in a bipolar low polarization lead. PDI is a new algorithm designed for ER detection when a bipolar primary pulse configuration is selected. Since the DMax algorithm for ER detection has been used in all the published studies, unipolar stimulation configuration was programmed in all the patients included in the study. Patients programmed in bipolar stimulation configuration were excluded.

From January to December 2012, all the subsequent scheduled pacemaker check-ups were reviewed. Clinical data and pacemaker stimulation parameters were recorded. Patients showing lead dysfunction, described as the presence of abnormal impedance or noise, were excluded. High stimulation threshold was not considered as exclusion criteria.

Data analysis

Long-term AutoCapture function reports were evaluated in all patients. These reports show long-term values of AutoCapture threshold, its variability along time, and the presence of values out-of-range. Two patterns were described: normal and abnormal AutoCapture patterns. Normal AutoCapture pattern was defined as the presence of stable values of AutoCapture thresholds along time, with lack of significant variability (variations ≤ 1 V in stimulation threshold) and no out-of-range values. Abnormal AutoCapture pattern was defined as the presence of a high variability of the AutoCapture threshold values along time (≥ 5 variations > 1 V in stimulation threshold) and/or the presence of repeated out-of-range values (≥ 5 episodes).

Statistical analysis

Data were subjected to descriptive statistical analysis, via frequency measurements (absolute frequencies and percentages) for qualitative variables, and via means and standard deviations for quantitative variables. The magnitude of the effects of the variables was expressed in the form of odds ratio (OR) and 95% confidence interval limits (95% CI). Univariate analysis of the quantitative variables was performed using the Student’s t-test when their distribution was normal and the Mann–Whitney U test when they were not. The qualitative variables were analysed using the χ² or the Fisher’s exact test. We then performed a multivariate analysis (logistic regression) to determine significant predictors of an abnormal AutoCapture pattern. From the collection of baseline variables, those with the potential to act as confounding factors were selected first in terms of their clinical and biological plausibility, and second in terms of the statistical criterion of Mickey excluding all those variables that in univariate analysis returned an association with the response reflected by a value of P > 0.20. The selected variables were the following: age, sex, medication, rhythm and history of AF, pacemaker, percentage of ventricular pacing, stimulation threshold, R-wave detection, and type of lead (passive or active fixation). The results are expressed as OR and 95% CI.

Results

From January to December 2012, 160 consecutive patients (93 men, 55%) were included in the study. The mean age was 78 ± 9 years (range 33–98). In 110 patients (69%), there was no evidence of underlying structural heart disease. On the other hand, 26 patients (16%) showed ischaemic heart disease, 18 patients (11%) valvular heart disease, 5 patients (3%) hypertrophic cardiomypathy, and 1 patient (0.6%) dilated non-ischaemic cardiomypathy. The mean left ventricular ejection fraction was 57 ± 7%. A history of AF was present in 97 patients (60%). At inclusion, AF was present in 44 patients (27.5%).

Thirty-five patients (22%) had a single-chamber VVI pacemaker and 125 patients (78%) a dual-chamber DDD pacemaker. Nine dual-chamber DDD pacemakers were programmed in VVI mode because of long-lasting chronic AF. Since the AutoCapture test is different in VVI or DDD mode, two groups were also analysed: 44 patients in VVI mode (27.5%) and 116 patients in DDD mode (72.5%). All the pacemakers were connected to low polarization leads. Ventricular passive-fixation leads were present in 145 patients (90%). Indications for pacing were sinus node disease in 58 patients (36%), AV block in 45 patients (28%), fast–slow AF in 50 patients (31%), syncope and bifascicular bundle branch block in 6 patients (4%), and vasovagal syncope in 1 patient (1%).

We also recorded the pharmacological treatments including anti-arrhythmic drugs, beta-blockers, calcium-channel blockers, digoxin,
and ivabradine. Renal function was also assessed showing normal renal function in 128 patients (80%), mild–moderate renal impairment in 25 patients (16%), and severe renal insufficiency (glomerular filtration rate < 30 mL/min/1.73 m²) in 7 patients (4%).

During the scheduled visits for pacemaker check-up in 2012, 87 patients (54.4%) showed a normal and effective long-term AutoCapture algorithm function. The mean percentage of ventricular pacing was 55 ± 40% (range 1–99%), impedance 447 ± 85 Ω (range 250–730 Ω), R-wave detection 9.8 ± 2.7 V, and AutoCapture stimulation threshold 0.81 ± 0.50 mV. DDD-mode patients showed AMS episodes in 88 patients (76%). Seventy-three patients (45.6%) showed abnormalities in the long-term AutoCapture function report. These patients exhibited frequent AutoCapture stimulation threshold values out-of-range and/or frequent out-of-range values as described before as abnormal AutoCapture pattern. Twenty-nine of these patients (39.7%) presented AF and the remaining 44 patients showed sinus rhythm. Sinus rhythm patients showing abnormal AutoCapture pattern presented ventricular pacing ≤ 25% in 29 patients (39.7%), >50 AMS episodes in 12 patients (16.4%), and >100 premature ventricular complexes (PVCs) episodes in 9 patients (12.3%).

The results of the univariate analysis are shown in Table 1. There were no statistical differences regarding history of AF, use of antiarhythmic drugs, renal function, active or passive lead fixation, R-wave detection, stimulation threshold, or electrode impedance. DDD mode and ventricular pacing ≥ 25% were associated to a normal AutoCapture pattern [OR 0.36 (0.18–0.74; P < 0.05) and OR 0.27 (0.13–0.54; P < 0.05), respectively]. Abnormal AutoCapture pattern was present in 12 patients (26%) with AV block indication and in 61 patients (53%) with other indications. In 45 patients with

![Figure 1](https://academic.oup.com/europace/article-abstract/16/10/1469/2426028)
AV block indication, abnormal AutoCapture pattern was present in 5 patients (62%) with VP ≤ 25% and 7 patients (33%) with VP ≤ 50% and in 7 patients (19%) with VP > 25% and 5 patients (15%) with VP > 50%. P = 0.017 and P = 0.011, respectively. Univariate analysis showed a lower risk of abnormal AutoCapture pattern in patients with AV block indication [OR 0.32 (0.15–0.69; P = 0.05)]. Patients showing AV block indication [OR 0.66 (0.28–1.56; P = 0.25)] were in AF at inclusion 3.16 (1.53–6.55). Only seven patients (13%) with ventricular pacing presented a mean ventricular pacing of 70.3%, compared with 36.7% ± 25% (only 2 patients exhibited a VP ≤ 50%, P = 0.011, respectively). After multivariate analysis, the presence of AF and low percentage of ventricular pacing (≤ 25%) were associated to a higher presence of abnormalities in the AutoCapture function. An abnormal AutoCapture pattern was present in 29 (65.9%) of AF patients and in 44 (37.9%) of non-AF patients [OR 3.16 (1.53–6.55; P < 0.05) and OR 7.20 (1.52–34.08; P < 0.05), respectively]. After multivariate analysis, the presence of AF and low percentage of ventricular pacing (≤ 25%) were associated to a higher presence of abnormalities in the AutoCapture function. An abnormal AutoCapture pattern was present in 29 (65.9%) of AF patients and in 44 (37.9%) of non-AF patients [OR 3.16 (1.53–6.55; P < 0.05)]. Patients showing normal AutoCapture pattern presented a mean ventricular pacing of 70.3 ± 38.5% compared with 36.7 ± 35.9% in patients with abnormal AutoCapture pattern, P < 0.05. Ventricular pacing ≤ 25% of the time was present in 54 patients (33.8%) and it was associated to a high risk of abnormal AutoCapture pattern [OR 4.80 (2.09–11.05; P < 0.05)]. Only seven patients (13%) with ventricular pacing ≤ 25% were in AF and these patients showed abnormal AutoCapture pattern. Then, the remaining 22 patients in AF with abnormal AutoCapture pattern had a VP > 25% (only 2 patients exhibited a VP > 90%). There were no differences regarding other clinical variables.

In some patients with very low stimulation thresholds, we made an additional striking observation. In three patients (1.8%), the AutoCapture algorithm detected captures at nominal outputs of 0.0 V during the automatic threshold test, a situation that disables the AutoCapture algorithm and sets the pacemaker output at 5 V, thus compromising the long-term duration of the batteries. We have described this phenomenon in detail elsewhere.4

During the study period, no clinical complications related to the pacemaker settings were observed.

**Discussion**

In 1994, the first AutoCapture-featured single-chamber pacemaker was released by Pacesetter—St Jude, and over one million units have now been implanted worldwide, being the most extensively studied system for automatic verification of capture.7

The AutoCapture Pacing System determines whether a delivered pacing stimulus results in stimulation of the myocardium, and, consequently, adapts pacing output according to the measured threshold. There are two methods to recognize the ER after a ventricular paced beat depending on the configuration in unipolar (DMax algorithm) or bipolar (PDI algorithm) stimulation. The DMax algorithm determines the maximum slope of the ER response by calculating the difference between alternate samples (14 samples) after unipolar paced beats. All the studies that have evaluated the AutoCapture algorithm have used this ER detection method.

The AutoCapture algorithm increases patient safety by confirming capture after every ventricular paced beat and allowing for high-output backup pacing if a loss of capture is detected. In addition, it offers a more efficient use of the pacemaker battery increasing the longevity of the device by reducing the energy delivered during stimulation to the minimum required (+0.25 V above the stimulation threshold). Once the algorithm is activated, AutoCapture threshold tests are automatically performed with a programmable periodicity (every 8 or 24 h). However, AutoCapture works different in VVIR units and DDDR units. In VVIR programmed units, the AutoCapture threshold test is only performed if there is ventricular pacing at the precise moment of the test, it does not overdrive intrinsic rhythm in this situation. In the DDDR units, it is performed whenever it is programmed shortening the AV interval automatically up to 50 ms during the test to assure capture. During theAMS, the DDDR units work like VVIR units do.8 In our study, the univariate analysis showed differences between DDD mode and VVI mode [OR 0.36 (0.18–0.74)]. DDD units were not likely to underperform owing to the dedicated fusion avoidance algorithm for AutoCapture while VVI units may underperform when a competing rhythm causing fusion is present.

AutoCapture safety was reproducibly demonstrated in studies showing that an effective backup pulse always followed a loss of capture. A high correlation between automatically and manually determined thresholds has been also uniformly reported.9–12

Pulse amplitude and pulse width are the two most important parameters influencing battery current drain and device longevity. In St Jude Medical pacemakers, when the pulse amplitude is programmed above the nominal value of 2.5 V, a voltage doubler is used in the circuitry of the device to ‘pump-up’ the output voltage above 2.8 V (unloaded voltage) supplied by the lithium iodine battery. Engaging this voltage doubler can significantly increase the battery current drain. Similarly, when the pulse amplitude is set above 5.0 V, a voltage tripler is used to achieve the desired output and results in a further increase in battery current drain.13 In patients with pacing thresholds over 1.5 V, a conventional ‘x2 safety margin’ programming
AutoCapture limitations in patients with cardiac stimulations devices

reduces significantly the battery longevity compared with ‘0.25 V above threshold’ programming. In reported longevity studies, the expected benefit of AutoCapture with respect to a fixed output with a 100% ‘x2safety margin’ was over 12 months in this subgroup of patients. The higher the stimulation threshold and the percentage of stimulation are, the higher is the benefit of the AutoCapture algorithm saving energy and prolonging the longevity of the device.

On the other hand, our study shows some situations where the AutoCapture does not seem so effective. Thus, 65.9% of patients in AF showed abnormal AutoCapture patterns during follow-up. The presence of sensed and fusion beats during the AutoCapture threshold test could interfere in the correct development of the algorithm showing a great variability in the threshold values. This situation could be more critical in patients with AF and low percentage of ventricular pacing, since ventricular sensed beats interfere more easily during the threshold test. Moreover, in patients with a ventricular pacing ≤25% (33.8%), this abnormal pattern was more frequently observed. But these abnormalities in long-term AutoCapture functioning reports can also be observed in patients in sinus rhythm and high percentage of ventricular pacing. Then, presumably more than one mechanism might be responsible in different patients. Fusion is a plausible mechanism in patients with low percentage of ventricular pacing, but we have observed abnormal patterns also in patients with high percentage of ventricular pacing. Maybe in these patients other mechanisms like the presence of a high density of ventricular premature beats could also interfere during the AutoCapture tests or recurrences of paroxysmal AF (Figure 2). Sinus rhythm patients showing abnormal AutoCapture patterns presented ventricular pacing ≤25% in 29 patients (39.7%), >50 AMS episodes in 12 patients (16.4%), and >100 PVC episodes in 9 patients (12.3%). Two or more coexisting circumstances were identified in 12 patients (16.4%). Finally, other important situation is the anomalous phenomenon described in patients with low stimulation threshold, where the test is abnormally performed and high-energy stimulation is automatically programmed. In all these situations, the result is that the output threshold is overestimated or considered abnormal and the device is programmed 0.25 V over an overestimated threshold or in a high-energy (5 V) stimulation, respectively (Figure 3). No reasonable explanation for abnormal AutoCapture pattern was found in seven patients (9.5%).

Patients showing a high stimulation threshold and a high percentage of stimulation beats are those that benefit most from the AutoCapture algorithm. In patients showing abnormal AutoCapture patterns and low percentage of stimulation or very low stimulation thresholds benefit is more questionable. On the other hand, these patients might benefit in terms of safety by beat-to-beat capture confirmation, although it can result in an increase in battery consumption.

During the routine follow-up of cardiac electronic devices where AutoCapture is activated, it is mandatory to check the long-term AutoCapture stimulation threshold to confirm the correct functioning of this algorithm. In our institution, in patients showing abnormal AutoCapture patterns, this function was disabled or not attending to safety or efficiency criteria analysed in each case.

Limitations

The present study has the limitations associated to observational single-centre studies. On the other hand, the study includes a ‘real life’ highly reproducible pacemaker population where an exhaustive evaluation of the programmer data and the AutoCapture algorithm has been performed, without interfering in other settings of the devices attending to the clinical characteristics of the patients.

The population included in our study differs from those described in previous studies, where AV block was the main indication in more than 60% of patients and previous history of AF was less prevalent. In our series, many ‘slow AF’ and ‘syncope and bifascicular BBB’ also presume forms of paroxysmal AV block. Differences could be related with how the diagnoses were defined. In our study, only 44 patients (27%) were in AF at inclusion, although 97 patients (60%) had history of previous AF. In our opinion, it is not strange taking into account that the mean age was near 80 years old, 31% of patients...

**Figure 2** Composition illustrating the case of a patient (#113) changing from normal AutoCapture pattern to abnormal pattern in relation with a recurrence of AF. This patient had history of paroxysmal AF and a DDD pacemaker because of sick sinus disease. The programmer report shows the beginning of a prolonged automatic mode switch episode coinciding with the change of AutoCapture pattern.
The programmed parameters, telemetry usage, and other factors affect the episodes of out-of-range values to clarify the responsible cause. Another limitation is the absence of stored electrograms; therefore, battery consumption in these circumstances cannot be estimated. Additional limitation is the absence of stored electrograms of the episodes of out-of-range values to clarify the responsible cause (AF, ventricular premature beats, fusion, etc.).

Abnormal AutoCapture pattern represents the variability in the stimulation threshold during the follow-up and/or the presence of out-of-range values that theoretically imply high-voltage backup stimulation. Programmer report data regarding duration of high-voltage stimulation or mean stimulation threshold are not available. Therefore, battery consumption in these circumstances cannot be estimated. Another limitation is the absence of stored electrograms of the episodes of out-of-range values to clarify the responsible cause (AF, ventricular premature beats, fusion, etc.).

Pacemaker programmer taking into account the battery voltage, the programmed parameters, telemetry usage, and other factors affecting current drain at the moment of interrogation estimates the device longevity. Therefore, only when an abnormal AutoCapture stimulation threshold is present at the moment of the check-up, it would be possible, in some cases, to increase the device longevity deactivating the algorithm and programming the traditional ‘x2 safety margin’.

Finally, our study has only evaluated the AutoCapture algorithm incorporated in St Jude Medical devices with DMax algorithm for ER detection. St Jude Medical PDI algorithm and algorithms developed by other cardiac devices companies show functioning differences; therefore, our data are not translatable to these devices that should be evaluated in future studies.

**Conclusions**

The AutoCapture™ Pacing System automatically adapts the ventricular output to capture threshold increasing the patient safety and pacing system longevity. This algorithm is really useful in those patients that benefit most (i) in terms of saving energy: patients with high stimulation threshold (output over 2.5 V) or high percentage of ventricular stimulation; or (ii) in terms of safety: patients showing some kind of electrode dysfunction where capture should be assured. On the other hand, some patients might not benefit from it. Benefit in some patients with ventricular pacing ≤25%, low stimulation threshold, and/or AF could be more questionable and special attention should be paid to the long-term AutoCapture functioning reports. Activation of the algorithm should be individualized in each patient and long-term AutoCapture pattern must be checked routinely during follow-up.

**Conflict of interest:** none declared.

**References**

Accurate evaluation of para-Hisian pacing in a patient with fasciculoventricular bypass

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A 20-year-old man with palpitations and ventricular pre-excitation was referred for an electrophysiology study. Atrial extra-stimulations caused AH prolongation without changes in the degree of pre-excitation, suggesting a fasciculoventricular bypass tract. We performed para-His pacing that yielded two similar QRS morphologies. Low output stimulation captured only local ventricular myocardium (Vc) (Figures 1A and 2A). Higher output pacing captured the His bundle and local ventricular myocardium (H+Vc) (Figures 1B and 2B). The stimulus–right ventricular apex (RVA) interval was shorter for H+Vc than for Vc. The QRS morphology was identical to Vc. Higher output pacing captured only the His bundle (Hc). The stimulus to the RVA interval of Hc was identical to H+Vc, but the stimulus–local electrogram interval was longer. The QRS morphology was identical to sinus rhythm (Figure 1E). Isoproterenol infusion provoked junctional rhythm with QRS morphology, which was identical to sinus rhythm (Figures 1D and 2D). In the patients with fasciculoventricular bypass, QRS morphology of Vc was identical to H+Vc because this bypass connects to the para-Hisian area. To distinguish H+Vc from Vc, the stimulus on the RVA and local ventricular electrogram interval should be considered. If we cannot establish reliable ‘pure’ Hisian pacing, the junctional beats promoted by drug infusion can be used to elicit this bypass.

The full-length version of this report can be viewed at: http://www.escardio.org/communities/EHRA/publications/ep-case-reports/Documents/Accurate-evaluation-of-para-Hisian-pacing.pdf.

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