Superior Rhythm Discrimination With the SmartShock Technology Algorithm
— Results of the Implantable Defibrillator With Enhanced Features and Settings for Reduction of Inaccurate Detection (DEFENSE) Trial —

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Background: Shocks delivered by implanted anti-tachyarrhythmia devices, even when appropriate, lower the quality of life and survival. The new SmartShock Technology® (SST) discrimination algorithm was developed to prevent the delivery of inappropriate shock. This prospective, multicenter, observational study compared the rate of inaccurate detection of ventricular tachyarrhythmia using the SST vs. a conventional discrimination algorithm.

Methods and Results: Recipients of implantable cardioverter defibrillators (ICD) or cardiac resynchronization therapy defibrillators (CRT-D) equipped with the SST algorithm were enrolled and followed up every 6 months. The tachycardia detection rate was set at ≥150 beats/min with the SST algorithm. The primary endpoint was the time to first inaccurate detection of ventricular tachycardia (VT) with conventional vs. the SST discrimination algorithm, up to 2 years of follow-up. Between March 2012 and September 2013, 185 patients (mean age, 64.0±14.9 years; men, 74%; secondary prevention indication, 49.5%) were enrolled at 14 Japanese medical centers. Inaccurate detection was observed in 32 patients (17.6%) with the conventional, vs. in 19 patients (10.4%) with the SST algorithm. SST significantly lowered the rate of inaccurate detection by dual chamber devices (HR, 0.50; 95% CI: 0.263–0.950; P=0.034).

Conclusions: Compared with previous algorithms, the SST discrimination algorithm significantly lowered the rate of inaccurate detection of VT in recipients of dual-chamber ICD or CRT-D.

Key Words: Discrimination algorithm; Implantable cardioverter defibrillator; Inaccurate tachycardia detection; Inappropriate shock; SST algorithm

The delivery of appropriate or inappropriate shocks by implantable devices lowers the quality of life and increases mortality. The delivery of unnecessary shocks may be prevented by 3 different methods. First, the device may be programmed with a high ventricular tachycardia detection rate and a high number of intervals to detection.
(NID). Second, anti-tachycardia pacing (ATP) instead of shocks may be used to terminate ventricular tachycardia (VT). Third, special algorithms are available to eliminate the false detection of supraventricular tachycardia (SVT), lead noise, T-wave oversensing (TWOS) or to abort the shock delivery for a spontaneously terminated ventricular tachyarrhythmia. The programming of a high detection rate may accelerate a tachyarrhythmia and cause the delivery of an unnecessary shock. Therefore, a highly discriminative algorithm is essential to lower the risk of shock delivery. SmartShock Technology® (SST) by Medtronic (Minneapolis, MN, USA) is a new discrimination algorithm, which operates in conjunction with conventional algorithms. A recent computer modeling study confirmed its efficacy in the prevention of inappropriate treatment at high detection rate settings. The question, however, of whether the SST algorithm has additional functions, while also including enhancing algorithms, further lowers the rate of delivery of unnecessary shocks for detection of VT/VF by analyzing beat-by-beat basis, to distinguish ventricular from supraventricular tachyarrhythmia. Second, the Wavelet algorithm, available only in VR ICD/CRT-D, analyzes the atrial and ventricular rates, pattern, regularity and the A and V timing relationship on a beat-by-beat basis, to distinguish ventricular from supraventricular tachyarrhythmia. Third, the Wavelet algorithm, compared with conventional discrimination algorithms, further lowers the rate of delivery of unnecessary treatment remains unclear.

The aim of this clinical study was therefore to examine the added benefit of the SST algorithm in implantable cardioverter defibrillator (ICD) or cardiac resynchronization therapy defibrillator (CRT-D) recipients.

### Methods

#### Study Design

This study was designed as a prospective, multicenter, non-randomized, observational trial (DEFENSE Trial; UMIN-CTR#R000008332 registered on 1 February 2012), which enrolled consecutive recipients of ICD or CRT-D equipped with the SST algorithm, followed remotely or in the regular outpatient clinic every 6 months, up to 2 years after device implantation. The devices were interrogated at all scheduled and unscheduled follow-up visits. The study protocol was approved by the institutional review board of each participating center and all patients provided written informed consent to participate in the study.

#### Patients

The patients included in this study had a primary or secondary prevention indication for de novo implantation, replacement or upgrade of a single (VR) or dual (DR) chamber ICD or CRT-D equipped with the SST algorithm (Protecta XT ICD [DR, VR], Protecta XT CRT-D [DR] and Evera XT ICD [DR, VR]; Medtronic, MN, USA). Patients (1) whose device programming did not match the study requirements (Table 1); (2) who were unable to complete 2 years of follow-up; or (3) who were unable to provide informed consent, were excluded from the study.

#### Discrimination Algorithms

##### Conventional Algorithms

The conventional tachyarrhythmia discrimination algorithms included in DR vs. VR devices are dissimilar. First, the PR logic algorithm, available only in DR ICD/CRT-D, analyzes the atrial and ventricular rates, pattern, regularity and the A and V timing relationship on a beat-by-beat basis, to distinguish ventricular from supraventricular tachyarrhythmia. Second, the Wavelet algorithm, available only in VR ICD/CRT-D, compares the ongoing QRS waveform with the QRS template previously sampled and stored during normal rhythm. VT/ventricular fibrillation (VF) detection is withheld when the ongoing waveform matches the template to a sufficient degree. Third, the sudden onset criterion is used to detect sinus tachycardia, in which the heart rate is typically changing gradually. And fourth, the stability criterion is used to detect atrial fibrillation (AF) with rapid ventricular response by the irregularity of the RR intervals. The sudden onset and stability criteria are available in both the DR and VR devices.

##### SST Algorithm

The SST algorithm consists of 4 main components: (1) the PR logic and Wavelet algorithm, described earlier, are available together in DR devices; (2) the TWOS discriminator analyzes changes in signal amplitude, slew rate and patterns to distinguish R wave from T wave and lower the risk of inappropriate shock delivery due to TWOS; (3) Confirmation+ analyzes the rhythm to confirm the presence of VT/VF, after the detection of VT/VF, before a shock is delivered; if it is not confirmed, the shock is aborted and the device enters a phase of redetection; and (4) the Lead noise discriminator identifies oversensing due to noise artifacts and withholds the delivery of inappropriate shocks for detection of VT/VF by analyzing the far-field electrogram to validate near-field sensing and differentiate RV lead noise from VT/VF. The SST algorithm operates along with conventional algorithms to enhance their discriminative performance. Thus, the SST algorithm has additional functions, while also including

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**Table 1. Recommended Programming**

<table>
<thead>
<tr>
<th>Zone</th>
<th>Status</th>
<th>Criteria</th>
<th>Therapy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ventricular fibrillation</td>
<td>ON</td>
<td>Cycle length; no. intervals to detection</td>
<td>Physician discretion</td>
</tr>
<tr>
<td>Ventricular tachycardia</td>
<td>ON</td>
<td>Cycle length &lt;400 ms; No. intervals to: Detection: 16 Re-detection: 12</td>
<td>Physician discretion</td>
</tr>
<tr>
<td>SVT limit zone</td>
<td></td>
<td></td>
<td>Physician discretion</td>
</tr>
<tr>
<td>PR-Logic</td>
<td>ON</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wavelet</td>
<td>ON or Monitor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discriminator</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T-wave oversensing</td>
<td>ON</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lead noise</td>
<td>ON or ON+Timeout</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SVT, supraventricular tachycardia.
determined according to physician discretion. Most of the devices (74%), however, were programmed to the nominal setting of 260 ms (264±18 ms). The episodes detected by the device, including the electrograms and outcomes of the discrimination algorithms, were stored.

Rhythm Classification and Episodes Analysis
Figure 1 shows the decision tree used in the analysis of tachyarrhythmia episodes. We reviewed all episodes recorded by the devices, including the decisions of the discrimination algorithms. Episodes that the conventional discrimination algorithm classified as VT/fast VT/VF were analyzed. An independent adjudication committee (Appendix) reviewed the entire episode recorded by the device, to determine whether the discrimination as well as withholding was appropriate or inappropriate. When the Wavelet algorithm was programmed on “monitor”, the episodes were classified as withheld by the SST algorithm. Inaccurate detections with the SST algorithm (Figure 1A) were compared with inaccurate detections with the conventional algorithm, defined as inaccurate detections and appropriate withholding of false VT/VF by the SST algorithm. DR, dual chamber; F, false VT/VF; T, true VT/VF; TWOS, T-wave oversensing; VR, single chamber.

Endpoints
The primary endpoint was the time to first inaccurate
observed in 56 patients (30%).

**Device-Detected Ventricular Arrhythmia**

During a follow-up of 620±228 days, 821 episodes of VT, fast VT or VF were identified by the conventional algorithms in 69 patients. Among these 821 episodes, 608 (74%) were adjudicated by the Event Committee as true ventricular tachyarrhythmia and 213 (26%) were adjudicated as other episodes, including 26 AF/AFl, 178 episodes of sinus tachycardia or AT, and 9 episodes of TWOS.

**Primary Endpoint**

Inaccurate detection of ventricular tachyarrhythmia was observed in 32 patients (18%) with the conventional discrimination algorithm, and in 19 patients (10%) with the SST algorithm. Kaplan-Meier survival free from first inaccurate detection of ventricular tachyarrhythmia during the 2-year follow-up for the entire group is shown in Figure 3A. While the rate of inaccurate detection tended to be lower with the SST than with the conventional algorithm (HR, 0.56; 95% CI: 0.31–1.00), the difference did not reach statistical significance (P=0.051). In the DR device group, however, a statistically significant decrease (P=0.034) was observed in the rate of inaccurate detection of ventricular tachyarrhythmia by the SST compared with the conventional algorithm (HR, 0.50; 95% CI: 0.263–0.950; Figure 3B). In the VR device group, the 2-year rate of inaccurate detection of ventricular tachyarrhythmia by the SST algorithm was similar to that with the conventional algorithm (data not shown).

**Statistical Analysis**

Continuous variables are reported as mean±SD. Between-group comparisons were performed using Student’s t-test. Categorical variables are reported as counts and percentages. Event-free survival was measured using the Kaplan-Meier method. Hazard ratios (HR) were estimated using the Cox proportional hazards model with a baseline hazard unique to each individual. Incidence ratio was estimated with the multi-level Poisson regression model, and the logarithm of days of follow-up was included as an offset. P<0.05 was considered statistically significant. All analyses were performed using STATA version 14 (StataCorp LP, College Station, TX, USA).

**Results**

**Patients**

Between March 2012 and September 2013, 14 Japanese medical centers enrolled 185 consecutive patients in this study. After the exclusion of 3 patients whose follow-up data were missing, 182 patients were included in the final analysis (Figure 2, Table 2). DR devices were implanted in 152 patients (82%). Atrial tachyarrhythmia, including AF, atrial flutter (AFl) and atrial tachycardia (AT), were observed in 56 patients (30%).

**Table 3. Inaccurate Detection of Ventricular Tachyarrhythmia: 2-Year Follow-up**

<table>
<thead>
<tr>
<th>Cause of inaccurate detection</th>
<th>Conventional</th>
<th>SST</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atrial fibrillation/flutter</td>
<td>26 (12)</td>
<td>23 (14)</td>
<td>3 (13)</td>
</tr>
<tr>
<td>Other SV tachyarrhythmias</td>
<td>178 (84)</td>
<td>141 (86)</td>
<td>37 (21)</td>
</tr>
<tr>
<td>T-wave oversensing</td>
<td>9 (5)</td>
<td>0</td>
<td>9 (100)</td>
</tr>
<tr>
<td>Total</td>
<td>213</td>
<td>164</td>
<td>49 (23)</td>
</tr>
</tbody>
</table>

Data given as n (%). SST, SmartShock Technology; SV, supraventricular.
Secondarily Endpoints

**Inaccurate Detection** A total of 213 inaccurate detections of ventricular tachyarrhythmia occurred in the absence of SST algorithm during the entire follow-up period, representing a mean of 1.2±4.2 events/patient and a maximum of 45 events/patient (Table 3). In contrast, 164 inaccurate detections of ventricular tachyarrhythmia occurred with the SST algorithm, representing a mean of 0.9±4.2 events/patient and a maximum of 36 events/patient. The incidence rate ratio of SST to conventional algorithm was 0.77 (95% CI: 0.63–0.94; P=0.012). The incidence rate ratio in the DR device group was 0.70 (95% CI: 0.55–0.89; P=0.004). It is noteworthy that inaccurate detection due to TWOS was totally eliminated by the SST algorithm, and that due to AT/AF and other SVT was decreased by 11.5% and 20.8%, respectively.

The mean cycle length of the tachycardias incorrectly detected by the conventional algorithm was 365±40 ms, compared with a mean cycle length of 337±48 ms for the accurately detected tachycardias (P<0.001). The mean cycle length of the incorrectly detected tachycardias with the conventional vs. the SST algorithm was identical (365±40 ms vs. 365±40 ms).

**Inappropriate Withholding** A total of 8 episodes of inappropriate withholding by the Wavelet algorithm was recorded in 3 patients, of which 7 episodes were observed in 2 DR CRT-D recipients. The template-matching score fulfilled the Wavelet criterion, causing withholding despite an episode of VT. One episode ended spontaneously within 11 s and the others ended with burst pacing because the Wavelet algorithm was programmed on “monitor”.

**All-Cause Mortality** Over a mean follow-up of 214±162 days, 16 patients died; 7 of heart failure, 4 of septicemia, 1 of tuberculosis, and 4 of undetermined causes. One of these patients had experienced an inaccurate detection by the conventional discrimination algorithm.

**Discussion**

The major finding of this study is that there was a significant decrease in the rate of inaccurate detection of ventricular tachyarrhythmia by SST compared with conventional discriminating algorithms in DR device recipients. This superiority of SST was mainly attributable to the TWOS discriminator and Wavelet algorithms. These beneficial effects were confirmed clinically in the setting of a ventricular tachyarrhythmia detection rate ≥150 beats/min.

**Previous Studies**

Volosin et al described a computer modeling simulation study estimating the shock reduction rate by combining a new discrimination algorithm, greater NID and ATP preceding the shock.13 The percentage of patients who received inappropriate shock during 5 years was decreased by 15%, and the decrease in the proportion of shocks delivered for non-VT/VF episodes was 82%. It is particularly noteworthy that the computer model was applied only to episodes faster than 188 beats/min, using the data of the SCD-HeFT study.14 which enrolled patients with a primary prevention indication and a single detection zone.

Auricchio et al conducted a prospective, multicenter clinical trial to measure the rate of inappropriate shocks delivered in a large sample population, including patients with secondary prevention indications, and to estimate the benefit conferred by ICD/CRT-D equipped with the SST algorithm.19 They programmed the VF detection rate at 188 beats/min and left the VT therapy zone to physician discretion (59% of patients had VT zone therapy enabled). During 2 years of follow-up, 3.7% of DR and 4.8% of VR recipients received inappropriate therapy, including shocks, ATP or both. They concluded that the SST algorithm combined with the routine implementation of modern programming strategies was associated with a very low rate of inappropriate treatment delivery. The inclusion of a VT zone had no effect on the rate of inappropriate shock delivery. Therefore, they hypothesized that the discrimination algorithms prevented an increase in the delivery of inappropriate therapies in the VT zone. The performance of the SST algorithm, however, was not clinically validated in that study because of the absence of a control group with conventional algorithms.

To the best of our knowledge, this is the first prospective clinical study comparing the pure effects of the SST algorithm with conventional algorithms and controlled programming of the ICD at a slow detection rate. The setting of the tachycardia detection rate (>150 beats/min) and NID (16 cycles) was determined based on a previous study, which recommended a relatively slow detection rate.16 The present results are concordant with previous studies in terms of the contribution to inaccurate detection of ventricular tachyarrhythmia.

**Advantages of SST Over Conventional Algorithms**

The decrease in incorrect detection of ventricular tachyarrhythmias was mainly due to the newly added Wavelet algorithm in DR devices in order to distinguish ventricular from supraventricular tachyarrhythmias. While the TWOS discriminator algorithm is diagnostically highly capable, its impact was modest because only 9 TWOS were observed in 4 DR patients. In addition, no episode of lead noise discrimination or Confirmation+ algorithm was observed in this study. Wavelet has already been included in VR devices as a conventional algorithm. Therefore, compared with conventional algorithms, in the present study the DR device had an added advantage as a result of the SST algorithm.

**SST Algorithm: Inappropriate Withholding**

A total of 8 instances of inappropriate withholding were observed in 3 patients. Seven instances occurred in CRT-D recipients, perhaps because the template morphology of the CRT-D Wavelet algorithm is not automatically renewed, in contrast to the ICD, with automatic renewal of the template with its own complexes. Careful attention should be paid to the programming of the Wavelet algorithm in CRT-D recipients, in particular. To avoid inappropriate withholding by Wavelet algorithm, the following are recommended: (1) “monitor” setting before the confirmation of discrimination; (2) strict setting of matching threshold to the template; and (3) early discovery of inappropriate withholding by remote monitoring.

**Study Limitations**

The present sample size, especially that of the VR device group, was relatively small, and insufficient to reliably compare SST with conventional algorithms in VR devices. Second, the primary endpoint was inaccurate detection of ventricular tachyarrhythmias. A decrease in inaccurate detection is not equivalent to a decrease in inappropriate shock delivery. Third, there is a possibility that the present results depend on device settings such as tachycardia detection rate and/or NID. Finally, we analyzed only the epi-
sodes with intracardiac electrograms recorded by the devices in the present study.

Conclusions

Compared with conventional discrimination algorithms, the new SST significantly decreased the rate of inaccurate detection of ventricular tachyarrhythmias in DR ICD or CRT-D recipients. This additional feature may lower the rate of inappropriate shock delivery in clinical practice.

Acknowledgments

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Disclosures

The authors declare no conflict of interest.

Author Contributions

H.A., Y.O. and R.K. had full access to, and assume responsibility for the data and for the data analysis; they also conceived of and designed the study, drafted the manuscript, and supervised the study. H.A., Y.O., R.K., T.N., K.O., S.H. and K.Y. carried out data collection. H.A., Y.O., R.K., T.H., K.K., M.N., T.U., H.M., K.S., M.O., T.I., Y.K., H.A., Y.O. and Y.F. carried out the statistical analysis. All authors read and approved the final manuscript.

References


Appendix. Events Adjudication Committee

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