Catheter ablation of atrial tachyarrhythmias causing inappropriate implantable cardioverter-defibrillator shocks

Shinsuke Miyazaki1*, Hiroshi Taniguchi1, Shigeki Kusa1, Yuki Komatsu1, Noboru Ichihara1, Takamitsu Takagi1, Jin Iwasawa1, Akio Kuroi1, Hiroaki Nakamura1, Hitoshi Hachiy1, Kenzo Hirao2, and Yoshito Iesaka1

1Cardiology Division, Cardiovascular Center, Tsuchiura Kyodo Hospital, 11-7 Manabeshin-machi, Tsuchiura, Ibaraki 300-0053, Japan; and 2Heart Rhythm Center, Tokyo Medical and Dental University, Tokyo 113-8510, Japan

Received 19 March 2014; accepted after revision 10 June 2014; online publish-ahead-of-print 24 July 2014

Aims
Inappropriate shocks have been an important issue post-implantable cardioverter-defibrillator (ICD) implantation. Moreover, inappropriate ICD shocks are associated with increased mortality. The objective of this study was to evaluate the feasibility of catheter ablation therapy for atrial tachyarrhythmias (ATa) responsible for inappropriate shocks.

Methods and results
Among 108 consecutive patients who underwent ICD implantations, 22, 5, and 3 experienced inappropriate ICD shocks due to ATa, sinus tachycardia, and T-wave oversensing, respectively. Among the 22 patients with ATa, 18 patients (55 ± 10 years, 15 men, structural heart disease in 9) underwent catheter ablation of ATa causing inappropriate shocks. The median duration between the ICD implantation and first inappropriate shock was 10.0 (3.0–24.5) months. The ATa were atrial fibrillation (AF), atrial flutter (AFL), and atrioventricular nodal reentrant tachycardia in 14, 2, and 2 patients, respectively. One patient underwent an atrioventricular nodal ablation for persistent AF associated with a venous anomaly. Among 13 patients who underwent pulmonary vein antrum isolation, 10 (76.9%) were free from AF for a median of 21.0 (13–37.3) months after an average of 1.3 ± 0.5 procedures. In four patients with AFL or a supraventricular tachycardia, none had any arrhythmia recurrence for a median of 6.0 (3.3–93.5) months after a cavotricuspid isthmus or slow pathway ablation, respectively. There were no procedural complications. During the median follow-up of 19.0 (9.5–37.3) months after the last procedure, no patients experienced any inappropriate shocks.

Conclusion
Catheter ablation is a feasible therapeutic option for treating ATa responsible for inappropriate shock(s) in patients with ICD.

Keywords
Implantable cardioverter-defibrillator • Inappropriate shock • Catheter ablation • Atrial tachyarrhythmias

Introduction
An implantable cardioverter-defibrillator (ICD) is recommended in individuals at high risk of sudden cardiac death.1,2 Despite proven survival benefits, ICD treatment has drawbacks, one of the most important being shocks delivered for causes other than potentially life-threatening ventricular tachyarrhythmias.3–7 Inappropriate shocks, which result in multiple adverse effects,3–9 have been associated with an increased mortality independent of interim appropriate shocks.6,7 Inappropriate shocks may occur due to lead-related causes like lead fractures or insulation breaks, but, in the majority, they are caused by atrial arrhythmias with rapid ventricular conduction. In 2001, Korte et al.10 showed that catheter ablation of Type 1 atrial flutter (AFL) and atrioventricular (AV) node modification for atrial fibrillation (AF) could decrease inappropriate shocks due to atrial tachyarrhythmias (ATa). However, few reports have systemically evaluated the utility of the catheter ablation of ATa causing inappropriate shocks despite substantial progression in ablation therapy of...
What’s new?

- After the implantation of an implantable cardioverter-defibrillator, various atrial tachyarrhythmias could cause inappropriate shocks.
- For the last decade, with the development of ablation therapies, the vast majority of atrial tachyarrhythmias causing inappropriate shocks are able to be treated by catheter ablation.
- Catheter ablation is a feasible therapeutic option for treating atrial tachyarrhythmias responsible for inappropriate shocks in patients with implantable cardioverter-defibrillators.

atrial arrhythmias over the past decade. The purpose of the current study was to evaluate the feasibility of catheter ablation of ATa causing inappropriate shocks in patients with an ICD.

Methods

Study population

The study population consisted of 108 consecutive patients who underwent an ICD implantation in Tsuchiya Kyodo Hospital between 2002 and 2011 according to the published guidelines13 (Table 1). The patients with cardiac resynchronization therapy were not included in the present study. The ICD implantations were directed by an experienced electrophysiologist. All patients were followed at 3 month intervals with interrogation of the device at our institution. If an inappropriate shock was observed during the follow-up period, we analysed its mechanism. If an atrial arrhythmia with a rapid ventricular rhythm was responsible for the inappropriate shock, we proposed catheter ablation as one of the therapeutic options to avoid such shocks in the future. Atrial fibrillation was defined according to the HRS/EHRA/ECAS 2012 Consensus Statement on Catheter and Surgical Ablation of AF.

Electrophysiological study

The surface electrocardiogram (ECG) and bipolar intracardiac electrograms were continuously monitored and stored on a computer-based digital recording system (LabSystem PRO, Bard Electrophysiology). Bipolar electrograms were filtered from 30 to 500 Hz.

All patients with AF were anticoagulated with warfarin for at least 1 month before the ablation procedure [target international normalized ratio (INR) 2–3], and therapeutic anticoagulation was maintained with intravenous heparin following the warfarin discontinuation 3 days prior to the intervention. Transoesophageal echocardiography was performed within 24 h pre-procedurally to exclude any left atrial (LA) thrombus. Warfarin was restarted on the day of the procedure and effective anticoagulation was maintained with heparin until the INR was >2.0. Enhanced cardiac computed tomography was performed for the evaluation of any relevant cardiac anatomy before the procedure. A 7Fr 20-pole or 14-pole two-site mapping catheter (Irvine Biomedical Inc.) was inserted through the right jugular vein and positioned in the coronary sinus (CS) for pacing, recording, and internal cardioversion. The electrophysiological study was performed under mild sedation with pentazocine and hydroxyzine pamoate.

For the patients with AFL and supraventricular tachycardia (SVT), venous access was obtained under local anaesthesia from the right femoral and subclavian veins to introduce two or four electrode catheters. One decapolar catheter was positioned in the lateral right atrium (RA) along the tricuspid annulus in patients with AFL. Three quadripolar catheters were positioned in the RA, His bundle region, and right ventricle in patients with SVT. A decapolar catheter was introduced from the right subclavian vein and positioned within the CS.

Catheter ablation protocol

In patients with AF, after one transseptal puncture, two long sheaths (SL0, SLJ) were introduced into both superior pulmonary veins (PVs).14 Pulmonary venography during ventricular pacing and contrast oesophagography were performed to obtain the relative locations of the PV ostia via a vis oesophagus. A 100 IU/kg body weight of heparin was administered following the transseptal puncture, and heparinized saline was additionally infused to maintain the activated clotting time at 300 – 350 s. The ipsilateral PVs and PV antrums were circumferentially ablated under the guidance of a three-dimensional mapping system15 (CARTO3, Biosense-Webster) with the double-Lasso technique. Pulmonary vein antrum isolation (PVAI) was defined as bidirectional conduction block between the LA and PVs. Radiofrequency (RF) current was delivered point-by-point for 30 s with a 3.5 mm externally irrigated-tip ablation catheter (Thermocool, Biosense-Webster) with a power of up to 35 W, target temperature of ≤38 °C, and irrigation rate of 30 mL/min. The power was limited to 20 W on the posterior wall. If AF continued after this step, the patients underwent internal electrical cardioversion. Non-PV foci were eliminated by additional ablation if they were identified. In patients with recurrence of atrial arrhythmias, the electrical PV isolation was evaluated first. In the presence of conduction recovery, a re-ablation of the PVs was performed.

In patients with atrial tachycardia (AT) and AFL, the arrhythmia was mapped using activation mapping and entrainment manoeuvres and ablated.16 When a critical isthmus of a macroreentrant circuit was identified, the lesions were deployed to achieve complete bidirectional conduction block. If the mechanism was cavotricuspid isthmus- (CTI) dependent AFL, a CTI line was created with an endpoint of bidirectional conduction block.17

In patients with AV nodal reentrant tachycardia (AVNRT), a slow pathway (SP) ablation was performed in the conventional SP region at the inferoseptal RA between the tricuspid annulus and CS ostium during sinus rhythm targeting the SP potential. Radiofrequency energy was applied with a 4 mm non-irrigated ablation catheter (Ablaze, Japan Life Line) in a temperature-controlled mode with a target temperature of 50–55 °C, and maximal power output of 40 W. The ablation endpoint

<table>
<thead>
<tr>
<th>Table 1 Patient characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
</tr>
<tr>
<td>Age at ICD implant (years)</td>
</tr>
<tr>
<td>Male</td>
</tr>
<tr>
<td>Cardiac disease</td>
</tr>
<tr>
<td>Brugada syndrome</td>
</tr>
<tr>
<td>Idiopathic ventricular fibrillation</td>
</tr>
<tr>
<td>Long QT syndrome</td>
</tr>
<tr>
<td>Hypertrophic cardiomyopathy</td>
</tr>
<tr>
<td>Dilated cardiomyopathy</td>
</tr>
<tr>
<td>Arrhythmogenic right ventricular cardiomyopathy</td>
</tr>
<tr>
<td>Coronary artery disease</td>
</tr>
<tr>
<td>Cardiac sarcoidosis</td>
</tr>
<tr>
<td>Valvular heart disease</td>
</tr>
<tr>
<td>Others</td>
</tr>
</tbody>
</table>
was the non-inducibility of AVNRT with and without an isoproterenol infusion.
During the ablation procedure, the ICD therapy was turned off to avoid any inappropriate therapy due to RF noise. Just before and after each ablation procedure, the pacing threshold, sensing, and lead impedance were measured in all patients.

Programming the devices
The systems used were manufactured by Medtronic, Boston Scientific, and St Jude Medical. In all devices, the stability and sudden onset algorithms were activated to reduce the occurrence of inappropriate shocks. The tachycardia detection zones were programmed to recognize fibrillation and either one or two tachycardia zones. Additional discriminators were activated in dual-chamber ICDs.

Follow-up
All patients underwent an ICD interrogation every 3 months in our outpatient ICD clinic. Appropriate ICD shocks were defined as shocks delivered for ventricular tachycardia (VT) or ventricular fibrillation (VF), and inappropriate ICD shocks were defined as shocks delivered in the absence of documented ventricular arrhythmias. In addition, the patients were followed up at the outpatient clinic by a cardiologist every 3 months. The follow-up visit consisted of a clinical interview, ECG, and 24 h Holter monitoring. Recurrence of an atrial arrhythmia was defined as an episode of an atrial arrhythmia lasting >30 s. The programmed settings of the ICD were not changed before or after the ablation procedure.

Statistical analysis
Continuous variables are expressed as the mean ± standard deviation or median and interquartile range, depending on the normality of the distribution. A P-value < 0.05 indicated statistical significance.

Results

Patient characteristics
Among 108 consecutive patients (Table 1) who underwent an ICD implantation, 30 (27.8%) experienced inappropriate shocks during the follow-up period. The causes of the inappropriate shocks were atrial arrhythmias with a rapid ventricular response, sinus tachycardia, and T-wave oversensing in 22 (20.4%), 5 (4.6%), and 3 (2.8%) patients, respectively. Inappropriate shocks due to ATa occurred at a median of 10.0 (3.0–24.5) months after the ICD implantation. The ATa included paroxysmal AF in 16 (72.7%), persistent AF in 1 (4.5%), longstanding persistent AF in 1 (4.5%), and SVT in 4 (18.2%) patients.

Sinus tachycardia and T-wave oversensing were successfully treated by device re-programming and beta-blocker therapy. In four patients, AF could be controlled by medications (amiodarone or sotalol in three paroxysmal AF and beta-blocker in one persistent AF patient), thereby preventing inappropriate shocks. In the remaining 18 (60.0%) patients, catheter ablation was undertaken for the treatment of ATa. The clinical characteristics, medical therapy, and device programming of those 18 patients are shown in Tables 2 and 3. Nine (50.0%) patients had structural heart disease. Four (22.2%) patients received a single-chamber ICD system.

Catheter ablation
The antiarrhythmic drugs were not discontinued in patients undergoing the ablation procedure. In 14 (77.8%) patients with AF, a PVAI was successfully achieved in all but 1 patient. During the procedure, an arrhythmogenic PV was identified in three patients (left inferior PV...
in one and right superior PV in two). In one patient with paroxysmal AF, the AV junction was ablated via the right internal jugular vein because of the absence of an inferior vena. Additional CTI linear ablation was performed in nine patients. In one patient, isolation of an arrhythmogenic persistent left superior vena cava was added. In one post-coronary artery bypass graft patient, a linear lesion between the inferior vena cava and RA scar was created for an inducible incisional reentrant tachycardia.

Among four (18.2%) patients with regular SVTs, two had CTI-dependent AFL and two others had AVNRT during the electrophysiological study. A CTI linear block and SP ablation successfully treated those arrhythmias.

Among 13 patients who underwent a PVAI, a repeat ablation was undertaken for recurrent ATa in 4 (30.8%) (AF in 2 and AT in 2 patients) at a median of 4.0 (2.5–12.3) months after the initial procedure. A mean of 3.3 ± 0.6 PVs were reconnected and successfully re-isolated in three patients. The two ATs were diagnosed as an RA localized reentrant AT and PA–LA reentrant AT around the right superior PV post-PVAI. Both ATs were successfully eliminated in the second procedure. One patient with recovery of CTI linear block underwent a successful repeat CTI ablation. None of the patients experienced any procedural complications including those related to the device/lead.

**Clinical outcome**

Among 13 patients who underwent the PVAI, 10 (76.9%) were free from any atrial tachyarrhythmias for a median of 21.0 (13–37.3) months after an average of 1.3 ± 0.5 procedures. Among three patients with AF recurrences, one patient had longstanding persistent AF, and in another patient the recurrence was observed after stopping amiodarone due to amiodarone-induced hyperthyroidism. Among four patients with SVTs, none had any recurrences hitherto, at a median of 19.0 (9.5–37.3) months after the last ablation procedure (Figure 1).

**Discussion**

**Major findings**

The present study demonstrated that catheter ablation might be a feasible therapeutic option to treat ATa responsible for inappropriate shocks post-ICD implantation.

**Inappropriate shocks in patients with implantable cardioverter-defibrillators**

Recent trials have shown that inappropriate shocks are common in patients with ICDs.3–7 The cumulative incidence of inappropriate shocks was 7% at 1 year, 13% at 3 years, and 18% at the 5-year follow-up in a large population. Inappropriate shocks for atrial arrhythmias with rapid ventricular conduction, or for abnormal sensing, result in multiple adverse effects including an impaired quality of life, psychiatric disturbances, proarhythmias, and poor tolerance of life-saving ICD therapy.3–9 Moreover, inappropriate shocks were associated with an increased probability of death on follow-up.6,7 Several explanations for the increased risk of death have been considered such as myocardial injury; increased anxiety and depression associated with increased mortality; and the indirect result of AF. Coupled with the potential effects on the quality of life, this association with an
Catheter ablation and inappropriate ICD shocks

inappropriate VT detection can be divided into arrhythmia related, device errors, and environmental causes. Prior studies have shown that AF and AFL are the most common arrhythmia causes of inappropriate shocks, followed by SVT, and inappropriate sensing. 

Advanced algorithms, multiple sensing leads, and improved device programming can reduce inappropriate shocks. Although dual-chamber ICDs should perform better than single-chamber ICDs, the results were not universal. performed a prospective, randomized study to evaluate the performance of tachyarrhythmia detection algorithms in single- and dual-chamber ICDs, but did not find a significant reduction in the number of inappropriate arrhythmia classifications. showed a reduction in the per cent of total SVT episodes that were inappropriately classified as VT in the dual-chamber detection group. However, almost 30% of the SVT episodes were still misclassified despite the dual-chamber criteria, and further the total inappropriate shocks were not reduced in the dual-chamber arm. These data suggest that arrhythmia discrimination, in particular, for ATa with stable AV conduction is still challenging. In the present study also, the majority of the patients with inappropriate shocks had dual-chamber ICDs.

Although programming a higher detection rate likely reduces the detection of atrial arrhythmias and the misinterpretation of them as ventricular arrhythmias, it is clear that programming too high a rate cut off could lead to underdetection of relatively slow monomorphic VTs or underdetection of polymorphic ventricular arrhythmias or VF due to intermittent undersensing. While a combined beta-blocker and amiodarone therapy might reduce inappropriate shocks by inhibiting the AV conduction in AF, the role of medications in preventing inappropriate shocks is ambiguous, with a prior study failing to find beta-blocker therapy protective from inappropriate shocks in the MADIT II study. Since sodium channel blockers should not be used in patients with an impaired left ventricular function, structural heart disease, and Brugada syndrome, careful selection of antiarrhythmic drugs is essential.

Catheter ablation of atrial tachyarrhythmias causing inappropriate implantable cardioverter-defibrillator shocks

There have been few reports which describe the efficacy of catheter ablation of ATa causing inappropriate shocks. In 2001, reported the results of catheter ablation of drug-refractory AF in 12 patients and Type 1 AFL in 6 patients who had multiple inappropriate shocks. They demonstrated that the number of inappropriate shocks significantly decreased after an AV node modification for AF and a CTI linear ablation for AFL. Recently, performed catheter ablation for SVTs (AT, AFL, and AVNRT) causing inappropriate shocks in 30 patients. They reported that 95% of the patients who underwent a successful ablation had no further inappropriate ICD therapies. These data supported the usefulness of catheter ablation of SVTs causing inappropriate shocks.

In 1998, reported that PVs are the most important sources of triggers that initiate AF in patients with paroxysmal AF and catheter ablation emerged as a new treatment for AF. Nowadays, PVAI is an acceptable option for the treatment of drug-resistant paroxysmal AF. In persistent AF, however, its success rates have been lower. Published studies have reported that freedom from persistent AF occurs in 20–61% of cases and frequently requires multiple ablation procedures.

Despite considerable progress in the ICD device and leads, inappropriate ICD shocks continue to remain an important issue. The present data show that the majority of the patients who undergo catheter ablation of atrial arrhythmias including AF remain free from ensuing inappropriate ICD shocks without any complications. Although medications and device re-programming are important aspects of the management of inappropriate ICD shocks, the present data suggest that catheter ablation is a feasible therapeutic option to avoid further inappropriate shocks.

Clinical implications

In a clinical setting, inappropriate shocks could be avoided more easily in patients with persistent AF by a rate control therapy than in those with paroxysmal AF where a sudden change in the heart rate could result in an inappropriate device detection. Based on the published data, it seems reasonable to consider catheter ablation in patients with paroxysmal AF to avoid inappropriate shocks and the risk of antiarrhythmic drug toxicity. Despite a low success rate, selected patients with persistent or longstanding persistent AF with a favourable LA anatomy may also be the candidates for catheter ablation, although the data remain limited at this time.

Study limitation

There are several limitations in the present study. This is a retrospective single-centre study, and its population is relatively small. The study
design is non-randomized and no comparator was included in the study. The ICD programming was not protocol specified. A larger study with a long-term follow-up is necessary to understand if the elimination of ATa by catheter ablation can improve the prognosis of patients with an ICD.

Conclusions

Catheter ablation is a feasible therapeutic option for ATa responsible for inappropriate shocks in patients with an ICD.

Acknowledgements

We thank Ashok J. Shah and John Martin for their linguistic assistance in the preparation of this manuscript.

Conflict of interest: none declared.

References