Impact of Sinus Node Recovery Time after Long-Standing Atrial Fibrillation Termination on the Long-Term Outcome of Catheter Ablation

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Summary
Atrial electrical and structural remodeling is related to the perpetuation of atrial fibrillation (AF) subsequent to sinus node dysfunction. We investigated the relationship between AF recurrence after catheter ablation and sinus node dysfunction in long-standing persistent AF patients using the sinus node recovery time (SNRT) after defibrillation.

Fifty-one consecutive patients who underwent a first ablation for long-standing persistent AF were enrolled. Intracardiac cardioversion was applied before ablation in the absence of any antiarrhythmic drugs, and the power required to defibrillate, number, and SNRT after defibrillation were measured. All patients underwent the same designed radiofrequency catheter ablation procedure.

No patient required permanent pacemaker implantation due to sinus dysfunction after the ablation. During the follow-up period of 28.4 months (3.6-43.7), 35 out of 51 patients (69%) experienced an AF recurrence. The AF recurrence was significantly associated with an older age (60 ± 11 versus 52 ± 12 years in the non-recurrence group, \( P = 0.0196 \)), longer SNRT after defibrillation (1722 [1410-2656] versus 1295 [676-1651] msec, \( P = 0.0125 \)), and larger left atrial (LA) volume (59 ± 25 versus 41 ± 15 mL, \( P = 0.0119 \)). There were no significant differences in the AF duration, AF cycle length, and right and total atrial conduction times between the 2 groups. A longer SNRT after defibrillation (adjusted HR 2.13, 95%CI 1.16-3.71, \( P = 0.0152 \)) and larger LA volume (adjusted HR 1.03, 95%CI 1.01-1.04, \( P = 0.0054 \)) were independent predictors of AF recurrence after ablation.

Assessment of the SNRT after defibrillation may help to predict a successful ablation in patients with long-standing persistent AF.

Key words: Electrical remodeling, Sinus node dysfunction, Intracardiac cardioversion

Radiofrequency catheter ablation is one of the minimally invasive and common procedures for treating atrial fibrillation (AF). For persistent AF, although catheter ablation as a nonpharmacological therapy is considered if patients remain symptomatic with rate control, or are intolerant to pharmacological therapy or it is ineffective, there have been benefits of the restoration of sinus rhythm by catheter ablation, such as relief from symptoms and an improvement in cardiac contractile function.1,2

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Although the pathophysiological mechanism of AF is not completely understood, the progression of atrial remodeling in AF has been shown to contribute significantly to the perpetuation of AF.3,4 Further, sinus node dysfunction (SND) occurs along with the presence of atrial remodeling in the upper part of the right atrium.5 Therefore, we hypothesized that patients with AF who have impaired sinus node function would have a lower success rate of catheter ablation of AF and that the sinus node recovery time (SNRT) after defibrillation from a long period of AF could be used to predict recurrences of AF after ablation. We, therefore, conducted a retrospective comparative study to investigate the impact of SND on long-term AF recurrence after ablation of long-standing persistent AF using the SNRT after defibrillation.

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Methods

Study patients: Fifty-one consecutive patients with non-valvular long-standing AF, in whom AF persisted for at least 1 year, and who had no previous recordings of sinus rhythm, that were referred to Nihon University Itabashi Hospital for radiofrequency catheter ablation between August 2010 and June 2014 were enrolled. Patients who underwent catheter ablation of AF or a permanent pacemaker implantation before, or who had a history of sick sinus syndrome (SSS), were excluded. All patients provided written informed consent for the electrophysiologic study and ablation. Adequate oral anticoagulation was given for at least 1 month before the procedure, and all antiarrhythmic drugs were withdrawn for at least 5 half-lives prior to the ablation. Upon admission, a physical examination, routine hematology and biochemistry tests, 12-lead electrocardiography (ECG), chest X-ray, and transthoracic and transesophageal echocardiography were performed. The maximum LA volume (by the prolate ellipsoid method) was determined, and the left ventricular ejection fraction (LVEF) was determined by M-mode echocardiography (Teichholz method). Before the ablation, all patients underwent multi-slice computed tomography for a 3-dimensional reconstruction of the left atrium (LA) and pulmonary veins (PV).

Cardioversion: Vascular access was obtained and a single trans-septal puncture was performed under sedation with an intravenous infusion of propofol and fentanyl as previously described. Eight second electrogram recordings were stored on a LabSystem PRO EP Recording System (Bard Electrophysiology, Lowell, MA, USA). The mean atrial fibrillatory cycle length (AFCL) measured from a 5-second local atrial electrogram was calculated using a Bard Lab Pro (Bard Electrophysiology). Intracardiac cardioversion (CV), using R-wave synchronized biphasic shocks, with a deflectable 20 pole catheter (BeeAT, 8 poles in the distal coronary sinus, 8 poles on the lateral right atrium, and 4 poles in the superior vena cava, Japan Lifeline Co., Ltd, Tokyo) was performed in all patients before the ablation. The shock current was delivered between the distal and middle sets of electrodes. The first shock was delivered at 15 J, and then the shock strength was increased to 20 J or 25 J when the defibrillation failed. A successful CV was defined as the restoration of sinus rhythm for more than 10 seconds after the cardioversion. The power needed to defibrillate, number of applied CVs, and SNRT after defibrillation were measured. The SNRT after defibrillation was defined as the time from the shock to the first signal recorded in the high right atrium (RA) (Figure 1).

Assessment of total atrial conduction time: Upon comprehensive transthoracic echocardiography with a Vivid q echocardiography system (GE Healthcare UK Ltd., Buckinghamshire, UK) on the day after the procedure, an apical 4-chamber view using Doppler tissue imaging was used to image the tricuspid annulus, and the time interval from the onset of the P wave in ECG lead II to the peak
a’ wave of the right lateral and left lateral atrial walls, and the wall on the tissue Doppler tracing was measured as the septal and total PA-TDI interval to assess the right and whole atrial conduction times as previously described. The measurements from 3 consecutive beats were averaged.

We also analyzed the standard 12-lead ECG in all patients. A resting ECG was obtained 2 - 4 weeks after the procedure, and the heart rate and PR interval were automatically measured by the ECG system.

Ablation procedure: All patients underwent the same ablation strategy with an EnSite NavX system (St. Jude Medical, St. Paul, MN, USA), and the recurrence of AF after ablation was assessed.

Following the CV, an extensive ipsilateral pulmonary vein isolation (PVI) was performed, guided by double Lasso catheters (Biosense Webster, Diamond Bar, CA, USA) with an irrigated catheter (Safire BLU, St. Jude Medical). The endpoint of the PVI was the achievement of complete entrance and exit block. In all patients, linear ablation of the LA roof, lateral and bottom, and/or a complex fractionated atrial electrogram based ablation in the LA were performed after the PVI as previously described. The endpoint of these steps was an LA linear ablation and abolition of all complex fractionated atrial electrograms in the LA. A cavo-tricuspid isthmus ablation was performed when a typical atrial flutter was induced by burst atrial pacing after the LA ablation.

Follow-up: All patients were followed up for at least 24 months after the ablation. The antiarrhythmic drugs were resumed after the procedure but then stopped after a 2-month post-ablation blanking period. The other prescribed drugs, including antihypertensives and statins, were continued during the follow-up period. A standard ECG and 24-hour Holter recording were scheduled during the follow-up period so that asymptomatic recurrences would not be missed. In addition, an ECG event recorder was used whenever a patient had any cardiac symptoms. Recurrence of AF was defined as AF lasting for more than 30 seconds on the standard ECG, ECG event monitor, or 24-hour Holter recording after the 2-month post-ablation blanking period.

Statistical analysis: The variables are expressed as the mean ± standard deviation or median and interquartile range. The chi-square test or Fisher’s exact test was used to compare the categorical variables, and the Student’s t test or Mann-Whitney U test for continuous variables for the tests of the differences between the 2 groups related to the presence of clinical variables and the post-ablation outcome. A correlation analysis was performed using the Spearman rank correlation coefficient. Cox hazard regression analysis was used to determine the clinical factors that were associated with the recurrence of AF. Variables with a P < 0.05 in the univariate models were included in the multivariate analysis. In the multiple Cox hazard model, log transformation was performed for the NT-proBNP levels and SNRT, which were skewed. To avoid any multicollinearity of the SNRT in the groups with and without an SNRT ≥ 2000 msec, we entered a group with an SNRT ≥ 2000 msec into the multivariate model. The cut-off values for the SNRT that best differentiated between the patients with and without AF recurrences were determined by a maximization of the hazard ratio algorithm. Receiver-operating characteristic (ROC) curves were constructed based on the SNRT after defibrillation and the area under the curve (AUC) was determined. The Kaplan-Meier method was used to analyze the AF recurrence free survival after the ablation and a log-rank test was performed. A P < 0.05 was considered statistically significant. All statistical analyses were performed with JMP 10 software (SAS Institute, Cary, NC, USA).

Results

Patient characteristics and SNRT after defibrillation: The correlations between the SNRT after defibrillation and the patient clinical characteristics, echocardiographic variables, electrophysiological data, and ablation results are shown in Table I. The SNRT was significantly longer in the female patients than in the male patients (2896 ± 5806 [2039-4515] versus 1482 ± 2181 [1203-2003] msec, P = 0.0044) and in the patients with AF recurrence after ablation than in those without (1722 ± 3197 [1410-2656] versus 1295 ± 1843 [676-1651] msec, P = 0.0110), respectively. There were no differences in the SNRT between the patients with and without other co-variables such as hypertension, diabetes mellitus, dyslipidemia, ischemic heart disease, and a prior history of stroke. A weak to moderate correlation was found between the SNRT and CV threshold (r = 0.3626, P = 0.0056), SNRT and number of CV (r = 0.4753, P = 0.0004), SNRT and LVEF (r = 0.2545, P = 0.0716), SNRT and AFCL (r = -0.3436, P = 0.0735), and SNRT and heart rate at follow-up (r = -0.2476, P = 0.0798). The SNRT did not correlate with the LA volume (r = 0.0909, P = 0.9485), right PA-TDI interval (r = -0.1597, P = 0.2783), or total PA-TDI interval (r = -0.0782, P = 0.5972). No correlation was found between the SNRT and any other of the continuous variables examined.

Ablation outcome: No one required a permanent pacemaker implantation due to SND after the ablation. One patient with a prolonged SNRT after the CV had sinus bradycardia following the termination of AF by ablation and was implanted with a temporary pacing wire for 2 days. All patients were completely followed up for at least 24 months after the ablation. AF recurred in 21 (41%) patients at 12 months and in 23 (45%) at 24 months after the ablation. During the final follow-up period of 28.4 (3.6-43.7) months, AF recurred in 35 (69 %) of the 51 patients. The patients with AF recurrence were older (60 ± 11 versus 52 ± 12 years, P = 0.0196), and had a significantly longer SNRT after the defibrillation (1722 ± 3197 [1410-2656] versus 1295 ± 1843 [676-1651] msec, P = 0.0125) and a larger LA volume (59 ± 25 versus 41 ± 15 mL, P = 0.0119) than patients without AF recurrence (Table II). There were no significant differences in the other variables, including the CV threshold and number of CVs between the 2 groups. A multivariate analysis revealed that a longer SNRT after the defibrillation (adjusted hazard ratio [HR] 2.13, 95% confidence interval [CI] 1.16-3.71, P = 0.0152) and larger LA volume (adjusted HR 1.03, 95%CI 1.01-1.04, P = 0.0054) were independently associated with AF recurrence after ablation (Table II). A cut-off
value of 2000 msec for the SNRT after the defibrillation was determined by a maximum hazard ratio algorithm. In the multivariate analysis, the prognostic performance of an SNRT ≥ 2000 msec for an AF recurrence was significant (adjusted HR 3.65, 95%CI 1.49-8.74, P = 0.0054) after adjustment for the other significant variables by a univariate model. An ROC curve showed that the diagnostic accuracy of the CSNRT was limited and the conventional CSNRT had a poor predictive value for identifying AF patients with symptomatic bradycardia. The concept of assessing the SNRT after defibrillation in this study, in which the time from the shock artifact to the earliest sinus node activity after overdrive suppression of lasting AF is measured, can be considered to be the same as an estimation of the sinus node function by burst pacing maneuvers. Taking into account that the CSNRT determined by an EPS is invasive, this method is easy applicable for daily ablation procedures. Moreover, it can be applied in the daily practice with the 12-lead ECG and an external defibrillator to predict the results and determine the indications for AF ablation.

Discussion

The main finding of this study was that there was no strong relationship between the parameters implicating atrial remodeling, such as the atrial conduction time or LA volume and SNRT, while a weak-to-moderate correlation was found between the CV joules/number, LVEF, heart rate during the follow-up, and AF cycle length during the AF and the SNRT among the patients with longstanding persistent AF. Second, AF recurrence after the ablation was more prevalent in patients with a relatively longer SNRT after the defibrillation than in those without a longer SNRT. A long SNRT and large LA volume were independently associated with a long-term AF recurrence after a multivariate adjustment.

Diagnosis of sinus node dysfunction: Generally, SND is diagnosed by an invasive electrophysiologic study (EPS) with burst pacing maneuvers for SNRT and corrected SNRT (CSNRT) measurements, however, a previous study showed that the diagnostic accuracy of the CSNRT was limited and the conventional CSNRT had a poor predictive value for identifying AF patients with symptomatic bradycardia. The concept of assessing the SNRT after defibrillation in this study, in which the time from the shock artifact to the earliest sinus node activity after overdrive suppression of lasting AF is measured, can be considered to be the same as an estimation of the sinus node function by burst pacing maneuvers. Taking into account that the CSNRT determined by an EPS is invasive, this method is easy applicable for daily ablation procedures. Moreover, it can be applied in the daily practice with the 12-lead ECG and an external defibrillator to predict the results and determine the indications for AF ablation.

Substrate remodeling of sinus node function: In the present study, the SNRT after the defibrillation correlated well with female sex, CV number, and CV threshold. The association between the SNRT and female sex was supported by the clinical observation that SSS are more prevalent in woman than in men. One possibility of the strong association between the SNRT and CV number or CV threshold was that a lot of energy flowed to the sinus node and induced great electric damage to the node,
and thus resulted in a prolonged SNRT. However, AF recurrence was significantly associated with a long SNRT (1564 versus 1287 msec, $P = 0.0190$), even among the patients in whom a successful CV was achieved by a single CV with a low energy of 15 joules, suggesting a sinus node substrate vulnerable to AF rather than the CV energy itself. In fact, Chang, et al. reported an association between the slow conduction along the crista terminalis and

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### Table II. Patient Characteristics between the Patients with and without Atrial Fibrillation Recurrence, and Univariate and Multivariate Cox Regression Models for the Prediction of AF Recurrence

<table>
<thead>
<tr>
<th>Variable</th>
<th>Yes $n = 35$</th>
<th>No $n = 16$</th>
<th>$P$</th>
<th>HR 95% CI</th>
<th>$P$</th>
<th>HR 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years</td>
<td>60 ± 11</td>
<td>52 ± 12</td>
<td>0.0196</td>
<td>1.03 (1.00-1.06)</td>
<td>0.0448</td>
<td>1.02 (0.99-1.06)</td>
</tr>
<tr>
<td>Female, n (%)</td>
<td>6 (17)</td>
<td>0 (0)</td>
<td>0.1592</td>
<td>2.79 (1.01-6.64)</td>
<td>0.0478</td>
<td>1.67 (0.52-5.00)</td>
</tr>
<tr>
<td>AF duration, years</td>
<td>5 (1.7-9.0)</td>
<td>5 (1.5-9.0)</td>
<td>0.7836</td>
<td>0.97 (0.87-1.08)</td>
<td>0.5464</td>
<td>0.97 (0.87-1.08)</td>
</tr>
<tr>
<td>Body mass index, kg/m²</td>
<td>23.9 ± 2.9</td>
<td>24.2 ± 3.4</td>
<td>0.2199</td>
<td>1.51 (0.76-3.15)</td>
<td>0.2429</td>
<td>1.51 (0.76-3.15)</td>
</tr>
<tr>
<td>Hypertension, n (%)</td>
<td>23 (66)</td>
<td>7 (44)</td>
<td>&gt; 0.9999</td>
<td>1.24 (0.46-2.79)</td>
<td>0.6474</td>
<td>1.24 (0.46-2.79)</td>
</tr>
<tr>
<td>Diabetes mellitus, n (%)</td>
<td>8 (23)</td>
<td>3 (19)</td>
<td>&gt; 0.9999</td>
<td>0.79 (0.33-1.68)</td>
<td>0.3743</td>
<td>0.79 (0.33-1.68)</td>
</tr>
<tr>
<td>Ischemic heart disease, n (%)</td>
<td>3 (9)</td>
<td>0 (0)</td>
<td>0.5429</td>
<td>1.03 (0.25-2.89)</td>
<td>0.9626</td>
<td>1.03 (0.25-2.89)</td>
</tr>
<tr>
<td>Stroke, n (%)</td>
<td>4 (11)</td>
<td>0 (0)</td>
<td>0.2952</td>
<td>2.81 (0.82-7.38)</td>
<td>0.0933</td>
<td>2.81 (0.82-7.38)</td>
</tr>
<tr>
<td>Heart failure, n (%)</td>
<td>9 (26)</td>
<td>2 (13)</td>
<td>0.4663</td>
<td>1.18 (0.52-2.43)</td>
<td>0.6969</td>
<td>1.18 (0.52-2.43)</td>
</tr>
<tr>
<td>LA volume, mL</td>
<td>59 ± 25</td>
<td>41 ± 15</td>
<td>0.0119</td>
<td>1.02 (1.01-1.04)</td>
<td>0.0055</td>
<td>1.03 (1.01-1.04)</td>
</tr>
<tr>
<td>LVEF, %</td>
<td>62 ± 13</td>
<td>66 ± 8</td>
<td>0.2269</td>
<td>0.97 (0.95-1.00)</td>
<td>0.0952</td>
<td>0.97 (0.95-1.00)</td>
</tr>
<tr>
<td>Right PA-TDI interval, ms</td>
<td>123 ± 22</td>
<td>126 ± 32</td>
<td>0.7314</td>
<td>1.00 (0.98-1.01)</td>
<td>0.5251</td>
<td>1.00 (0.98-1.01)</td>
</tr>
<tr>
<td>Total PA-TDI interval, ms</td>
<td>144 ± 30</td>
<td>136 ± 19</td>
<td>0.3322</td>
<td>1.00 (0.99-1.01)</td>
<td>0.9915</td>
<td>1.00 (0.99-1.01)</td>
</tr>
<tr>
<td>NT-proBNP, pg/mL</td>
<td>515 (231-881)</td>
<td>261 (122-560)</td>
<td>0.1248</td>
<td>1.82 (0.93-3.75)</td>
<td>0.0799</td>
<td>1.82 (0.93-3.75)</td>
</tr>
<tr>
<td>AF cycle length, ms</td>
<td>139 ± 19</td>
<td>146 ± 26</td>
<td>0.4495</td>
<td>0.99 (0.97-1.01)</td>
<td>0.3436</td>
<td>0.99 (0.97-1.01)</td>
</tr>
<tr>
<td>CV threshold, joules</td>
<td>15 (15-15)</td>
<td>15 (15-15)</td>
<td>0.7477</td>
<td>1.00 (0.84-1.14)</td>
<td>0.9444</td>
<td>1.00 (0.84-1.14)</td>
</tr>
<tr>
<td>CV number</td>
<td>1 (1-1)</td>
<td>1 (1-1)</td>
<td>0.4031</td>
<td>1.34 (0.77-2.11)</td>
<td>0.2791</td>
<td>1.34 (0.77-2.11)</td>
</tr>
<tr>
<td>SNRT, ms</td>
<td>1722 (1410-2656)</td>
<td>1295 (676-1651)</td>
<td>0.0125</td>
<td>2.26 (1.33-3.72)</td>
<td>0.0028</td>
<td>2.13 (1.16-3.71)</td>
</tr>
<tr>
<td>Heart rate at follow-up, bpm</td>
<td>69 ± 12</td>
<td>75 ± 12</td>
<td>0.1329</td>
<td>0.98 (0.95-1.01)</td>
<td>0.359</td>
<td>0.98 (0.95-1.01)</td>
</tr>
<tr>
<td>PR interval, ms</td>
<td>169 ± 34</td>
<td>156 ± 20</td>
<td>0.1783</td>
<td>1.00 (0.99-1.01)</td>
<td>0.5730</td>
<td>1.00 (0.99-1.01)</td>
</tr>
</tbody>
</table>

Values are the mean ± SD, median (interquartile range), or n (%). $P$ values between the two groups were obtained using the Student t test, Mann-Whitney U test, chi-square test, or Fisher exact test. AF indicates atrial fibrillation; LA, left atrium; LVEF, left ventricular ejection fraction; PA-TDI, time from ECG lead II P-wave onset to septal/left atrial lateral a’ wave on tissue Doppler tracings; NT-proBNP, N-terminal pro-brain natriuretic peptide; CV, cardioversion; and SNRT, sinus node recovery time after defibrillation.

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**Figure 2.** Kaplan-Meier analysis of the atrial fibrillation recurrence according to the sinus node recovery time (SNRT) ≥ 2000 and < 2000 msec after defibrillation.
relatively low voltage near the sinus node area in patients with paroxysmal AF and SND as evidenced by the SNRT. Furthermore, it has been shown that patients with SND are associated with substrate abnormalities in the RA characterized by structural changes, altered conduction properties, and increased atrial refractoriness. Unexpectedly, the SNRT did not correlate with the septal and total PA-TDI, a surrogate of the right and left atrial activation times reflecting electrophysiologic remodeling, nor the LA volume, which reflected structural remodeling. The parameters used in this study were noninvasive tools for predicting the entire atrial electrical and structural damage, and thus, could not have determined regional RA remodeling, possibly because of a limited remodeling area around the sinus node. Similarly, even though comparative results have been shown between paroxysmal patients with and without symptomatic SSS, no significant association in terms of the LA diameters assessed by transthoracic echocardiography have been found.

Importantly, we found that both LA volume enlargement and prolonged SNRT were independently associated with long-term AF recurrence after multivariate adjustment. Atrial remodeling, evidenced by an LA volume enlargement, has been reported to be a major contributor to AF recurrences after ablation. Although this study did not provide any mechanistic insights into an explanation of the effect of a long SNRT on AF recurrence, we found that a slow heart rate during the follow-up was weakly correlated with a long SNRT after the defibrillation, which implicated mild SND. Hayashi, et al. found an interesting finding that paroxysmal AF patients clinically diagnosed with SSS had a significantly higher prevalence of non-pulmonary vein (non-PV) foci than those without SSS (25.9% versus 13.9%; \( P = 0.027 \)). In the multivariate analysis, congestive heart failure (HR, 13.7; 95% CI: 1.57-119; \( P = 0.02 \)) and non-PV foci (HR, 5.75; 95% CI: 1.69-19.6; \( P = 0.005 \)) were independent predictors of recurrence following AF ablation in the SSS group. Thus, the present study together with other reports suggested that a longer SNRT after the defibrillation in long-standing persistent AF patients may lead to AF recurrence after ablation, possibly due to multiple processes of a progressive electrophysiologic abnormality of the sinus node region, remodeled LA enlargement, and/or a high incidence of non-PV foci.

**Study limitations:** This study may be limited in several ways. First, it involved a small number of patients (\( n = 51 \)). Second, the standard SNRT during atrial overdrive pacing maneuvers was not measured after restoration of sinus rhythm, and it could have more precisely shown the function of the sinus node. However, it might not perfectly reflect the electrophysiological properties since it would have been performed just after restoration from a long period of AF. Third, activation and substrate mapping of the RA were not performed to demonstrate how much electrical and anatomical remodeling in the upper RA had occurred, which may have affected the sinus node function. Finally, the prognostic performance of the SNRT for AF recurrence was relatively high as evidenced by an AUC of over 0.70, however, we should take into account the fact that diagnostic errors can occur at a certain frequency.

**Conclusions**

A longer SNRT after defibrillation is associated with the recurrence of AF in the long-term period after ablation in patients with long-standing persistent AF. In these patients, the SND does not necessarily advance to SSS.

**Disclosures**

**Conflicts of interest:** None.

**References**