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High-power short-duration vs. conventional ablation in superior vena cava isolation

Igawa Wataru, MD, PhD[1]*; Koyanagi Yui, MD[1]; Yoshihiro Katsuya, MD[1]; Gibo Yuma, MD[1]; Usumoto Soichiro, MD[1]; Saito Jumpei, MD, PhD[2]; Ito Yuki, MD[1]; Okura Takeshi, MD[1]; Ochiai Masahiko, MD, PhD[1]

[1]Division of Cardiology, Showa University Northern Yokohama Hospital, Japan.

[2]Division of Cardiology, Yamanashi University Hospital, Japan.

[3]Division of Cardiology, Sakakibara Heart Institute, Japan.

[4]Clinical Research Institute for Clinical Pharmacology and Therapeutics, Showa University, Japan.

Corresponding Author: Wataru Igawa

Division of Cardiology, Showa University Northern Yokohama Hospital, 35-1 Chigasaki-Chuo Tsuzuki, Yokohama, Kanagawa, Japan.

Tel: +81-045-949-7000, Fax: +81-045-949-7117,
Email: igawa@med.showa-u.ac.jp

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Abstract

Introduction: The optimal ablation settings for Superior Vena Cava (SVC) isolation nremain unknown. This study examined the efficacy, feasibility, and safety of High-Power Short-Duration (HPSD) ablation for SVC isolation.

Methods: In total, 102 patients underwent SVC isolation for Atrial Fibrillation (AF). The first 51 patients underwent Lower-Power Long-Duration (LPLD) ablation, and the last 51 underwent ablation using the HPSD strategy. We compared the power, Radiofrequency (RF) duration, average CF, average local impedance drop, and Ablation Index (AI) between these groups.Regular follow-ups were conducted one, three, six, and 12 months postoperatively to identify AF recurrence.

Results: The HPSD group demonstrated significantly shorter procedure and RF times; lower mean CF, RF duration, and AI in both the lateral and septal segments; and greater impedance drop than the LPLD group. Additionally, the HPSD group showed a higher number of ablation sites involving the phrenic nerve. However, no increase in phrenic nerve injury or steam pops was observed. The AF recurrence rates were similar between the two groups at the 12-month follow-up.

Conclusion: The HPSD ablation strategy reduced the procedure time and did not increase complications. The rate of AF recurrence in the chronic phase was similar to that observed for conventional ablation.

Keywords: High-power short-duration ablation; Atrial fibrillation; Superior vena cava isolation; Phrenic nerve injury.

Abbreviations: 3D: Three-Dimensional; AF: Atrial Fibrillation; AI: Ablation Index; CF: Contact Force; CI: Confidence Interval; DOAC: Direct Oral Anticoagulant; ECG: Electrocardiogram; HR: Hazard Ratio; HPSD: High-Power Short-Duration; IQR: Interquartile Range; LPLD: Lower-Power Long-Duration; PFA: Pulse Field Ablation; PNI: Phrenic Nerve Injury; RA: Right Atrium; RF: Radiofrequency; SVC: Superior Vena Cava; SVCI: Superior Vena Cava Isolation; VISITAG: Ablation Tagging Module in CARTO3 Mapping System.

Introduction

Atrial Fibrillation (AF) is a majortype of arrhythmia and is widely treated with Radiofrequency (RF) catheter ablation. The Ablation Index (AI), which considers Contact Force (CF), power, and ablation time, is currently used to guide the creation of a permanent lesion. Although the pulmonary vein is the most common origin of AF, AF can also originate in the Superior Vena Cava (SVC), posterior wall of the left atrium, crista terminalis, coronary sinus ostium, ligament of Marshall, and interatrial septum [1]. SVC origin occurs in approximately 26%–30% of cases [2-4]. The effectiveness of electrical SVC Isolation (SVCI) has been reported [5,6]. However, the right lateral phrenic nerve is locatedon the lateral side of the SVC, and SVCI may cause

Phrenic Nerve Injury (PNI), SVC stenosis, and sinus node injury.

While previous studies have reported the efficacy and safety of High-Power Short-Duration (HPSD) ablation strategies for pulmonary vein isolation [7-9], the optimal RF power, duration, and AI setting on the SVC are unknown, and studies on HPSD ablation of the SVC are limited. Therefore, this study examined the effectiveness, practicality, and safety of HPSD ablation using Contact Force (CF)-sensing catheters for SVC isolation in AF treatment.

Materials and methods

Study population

This study comprised 102 patients diagnosed with AF and treated with catheter ablation of the SVC between February 2022 andJune 2023. Informed consent was obtained from all patients for the use of anonymized data for research purposes. The patients were categorized into two groups according to ablation method: HPSD ablation or Lower-Power Long-Duration (LPLD) ablation with the conventional setting. We performed LPLD for the initial 51patients and HPSD for the next 51 patients. AF type was classified according to the duration: paroxysmal AF lasting <1 week, persistent AF lasting >1 week, and longstanding persistent AF lasting >1 year.

SVC ablation protocol

All patients received Direct Oral Anticoagulants (DOAC) or warfar in for at least 3 weeks before the procedure. The operator decided whether to continue antiarrhythmic drugs.All patients received catheter ablation under general anesthesia using propofol, midazolam, and rocuronium. Heparin (15 0U/kg body weight) was administered after the puncture was completed and maintained at an activated clotting time of 300–400 s. Mapping and ablation utilized a Three-Dimensional (3D) mapping system (CARTO3 ®; Biosense Webster, Irvine, CA, USA). A duodecapolar catheter (BeeAT; Japan-Lifeline Co., Ltd.) was advanced into the coronary sinus through the internal jugular vein. A 20-pole catheter with five branches (Pentaray ®; Biosense Webster, Irvine, CA, USA) was utilized to create a 3D map of the SVC. A sinus node map was created before SVC isolation to confirm the sinus node location. The SVC was then divided into septal and lateralsegments. The ablation catheter was an irrigated-tip catheter (Thermocool SMARTTOUCH®; Biosense Webster, Irvine, CA, USA), and ablation was performed using point-by-point RF delivery starting at the septal side. On the lateral side, high-output pacing (10 V) was performed to locate the phrenic nerve, which was marked on the CARTO3 system. The endpoint of SVCI was defined by the absence of SVC potentials on a circular mapping catheter placed above the SVCI line and a bidirectional block from the Right Atrium (RA) to the SVC and from the SVC to the RA. First pass isolation was defined as isolation occurring before the ablation point (VISITAG, Biosense Webster) forming a complete circle; re-ablated points were not considered first pass isolation.

In the LPLD group, the RF energy was set to 25 W, whereas the AI settings were 300 and 250 for the septal and lateral sides, respectively. On the lateral side, RF energy was delivered, except at the phrenic nerve position; if not isolated, this position was also cauterized.

In the HPSD group, the RF energy was set at 50 W for 4 s for all SVC, including the phrenic nerve (Figure 1).

Analysis of the SVC lesion

The parameters of each ablation point (VISITAG, Biosense Webster) were compared between LPLD and HPSD groups, includingpower (W), RF duration (s), average CF (g), average local impedance drop (Ω), and AI (arbitrary unit). Each VISITAG size was 4 mm and appeared when the following parameters were met: a minimum CF of 3 g, 25% force over time, and minimum time of 3 s.

Study follow-up

All patients underwent echocardiography on the first postoperative day to assess cardiac function and to check for pericardial effusion. All patients underwent chest radiography preoperatively and on the first postoperative day to assess the occurrence of PNI, defined as postoperative elevation of the right diaphragm compared with the preoperative position. The blanking period was 90 days after the ablation. Anticoagulant therapy was maintained for a minimum of 90 days following the procedure. When the $CHADS_2$ score, including congestive heart failure, hypertension, age ≥75 years, diabetes mellitus, stroke, and transient ischemic attack (each contributing 2 points), was ≥2, the anticoagulant was continued. If the CHADS2 score was ≤1, the anticoagulant was discontinued. The decision to administer antiarrhythmic drug therapy was left to the operators. Follow-up visits were scheduled at one, three, six, and 12 months after the procedure. Twelve-lead electrocardiograms were obtained at the one-month visit, and 24-h Holter monitor recordings were conducted at the six- and 12-month follow-up visits. AF recurrence was defined as atrial arrhythmia, including AF, atrial flutter, and atrial tachycardia, recorded for >30 s on a 12-lead ECG or 24-h Holter monitor.

Statistical analysis

All data were analyzed using JMP 16 software (SAS Institute, Inc., Cary, NC, USA).

Continuous variables are presented as means ± standard deviation or medians ± the Interquartile Range (IQR) representing the 25^{th} – 75^{th} percentiles of data distribution. Categorical variables were tested using χ^2 or Fisher's exact tests. Statistical significance was set at P<0.05. The Cox proportional hazards model was used to estimate freedom from AF recurrence.

Results

Patient characteristics

Table 1 displays patient characteristics. Both the LPLD and HPSD groups included 20 and 31 patients with paroxysmal and persistent AF, respectively. While fewer patients in the HPSD group had congestive heart failure, the difference was not statistically significant.

SVC ablation

Table 2 shows the results of SVC ablation. The first-pass SVC isolation ratesdid not differ significantly between the LPLD and HPSD groups (90.2% vs. 91.6%). SVCI was achieved in all patients who underwent additional ablation, even those without SVC isolation after one round. The HPSD group had significantly shorter procedure and RF times than did the LPLD group. Conversely, the HPSD group had more ablation points that captured the phrenic nerve than the LPLD group (8 vs. 64, P<0.0001).

SVC ablation lesions

The ablation lesions in the septal and lateral segments are shown in Table 3 and Figure 2. In the septal segment, the HPSD group exhibited a lower average CF, shorter RF duration, lower AI, and greater impedance drop than the LPLD group. Similarly, in the lateral segment, the HPSD group had a lower average CF, shorter RF duration, and greater impedance drop, but a lower AI, than did the LPLD group. Compared with the LPDL group, the HPSD group had more ablation points that captured the phrenic nerve (8 vs. 64, P<0.0001).

Complications

Three patients experienced transient postoperative PNI (one in the LPLD group and two in the HPSD group), all of whom showed improved diaphragm elevation by 3 months postoperatively. No cases of pericardial tamponade, stroke, transient ischemic attack, steam pop, or death occurred in either group.

Comparison of arrhythmia-free survival between LPLD and HPSD ablation

All patients completed 12 months of follow-up. In the LPLD group, AF recurred in 11 patients, fourof whom underwent repeat ablation.In the HPSD group, AF recurred in 10 patients, nine of whom underwent repeat ablation. Figure 3 presents the Kaplan–Meier curves. The AF recurrence rates did not differ significantly between the two groups (Hazard Ratio [HR] 0.99, 95% Confidence Interval [CI] 0.64–1.54, P=0.95).With regard to patients who underwent a second ablation procedure, SVC recanalization was identified in two patients from the LPLD group and three from the HPSD group.

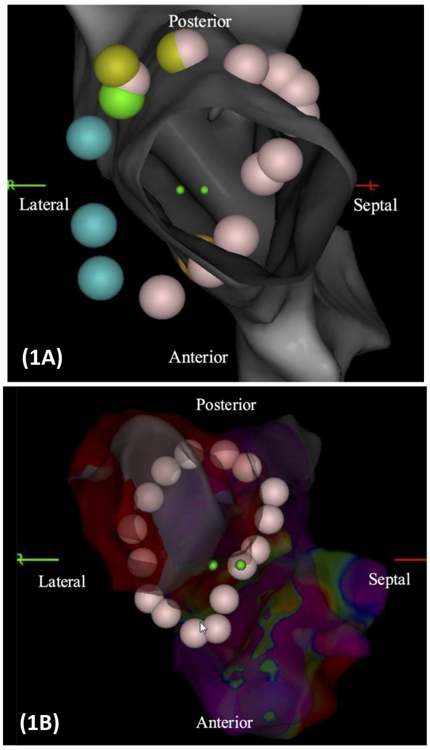

Figure 1: **(A,B)** Ablation using LPLD and HPSD. In LPLD, ablation was started on the septal side, with high output pacing on the lateral side; points capturing the phrenic nerve (yellow tag) were not ablated, whereas points not captured (blue tag) were ablated. If no isolation was achieved after one round, the yellow tag was ablated. Similarly, in HPSD, ablation was initiated on the septal side with high-output pacing on the lateral side, and a round of ablation was performed while confirming the point at which the phrenic nerve was to be trapped. LPLD: Lower-Power Long-Duration; HPSD: High-Power Short-Duration.

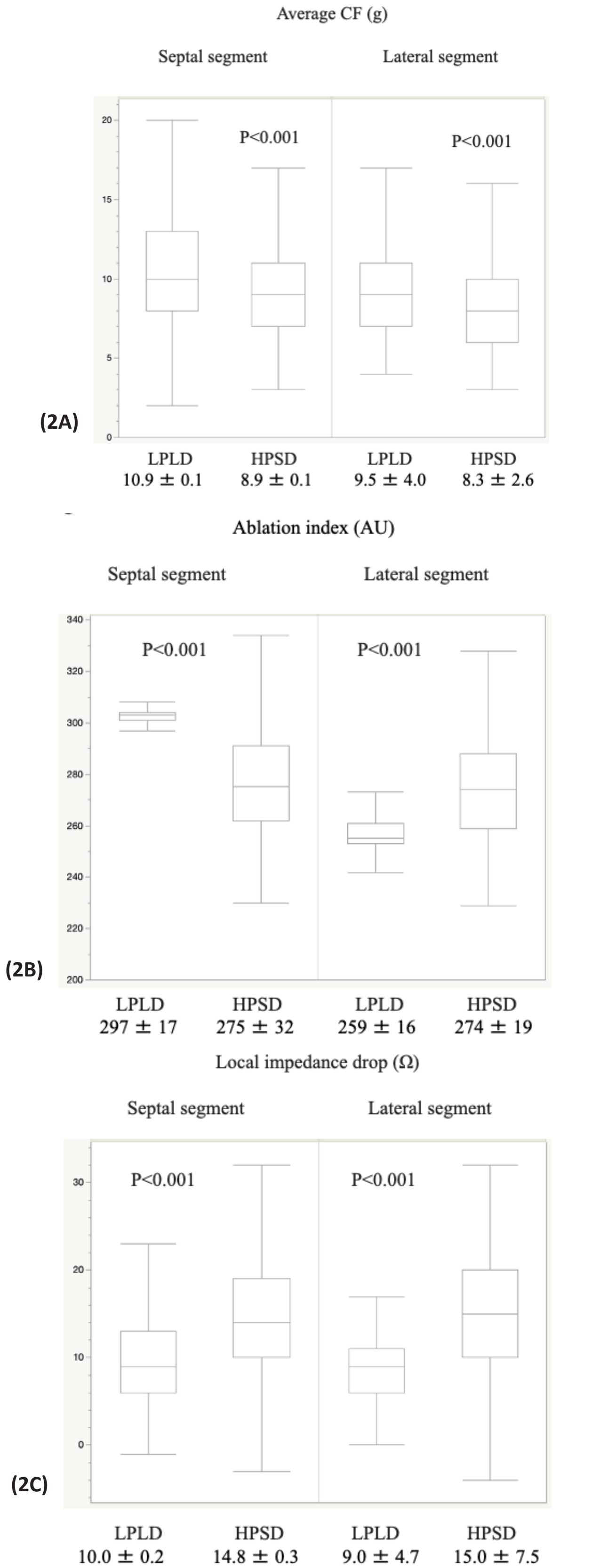

Figure 2: The average CF is lower in HPSD than in LPLD in both septal and lateral segments (septal segments: 10.9±0.1 vs. 8.9±0.1 g, P<0.001; lateral segments: 9.5±4.0 vs. 8.3±2.6 g, P<0.001). The mean ablation index islower in the septal segment and higher in the lateral segment in HPSD than in LPLD (septal segments: 297±17 vs. 275±32 AU, P<0.001; lateral segments: 259±16 vs. 274±19 AU, P<0.001). The mean local impedance drop isgreater in HPSD than in LPLD in both the septal and lateral segments (septal segments: 10.0±0.2 vs. 14.8±0.3 Ω, P<0.001; lateral segments: 9.0±4.7 vs. 15.0±7.5 Ω, P<0.001). CF: Contact Force; LPLD: Lower-Power Long-Duration; HPSD: High-Power Short-Duration.

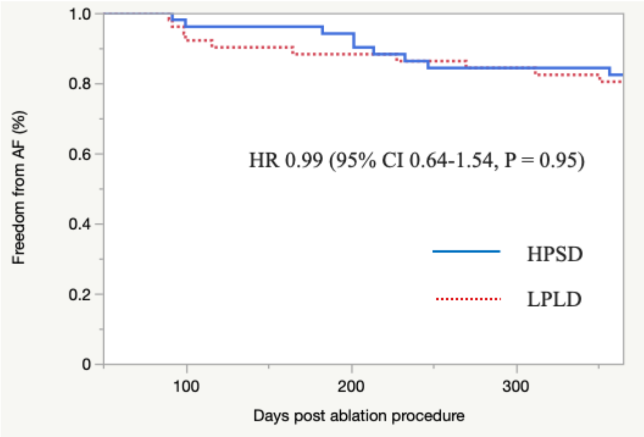

Figure 3: Kaplan–Meier estimates of freedom from AF. After the 90-day blanking period, AF recurred in 11 patients in the LPLD group and 10 patients in the HPSD group. Thus, HPSD was not inferior to LPLD (estimated one-year Kaplan–Meier event-free rates 78.4% and 80.4%, respectively; hazard ratio, 0.99; 95% Confidence Interval [CI], 0.64–1.54). AF: Atrial Fibrillation.

Table 1: Baseline patient characteristics.

	LPLD group (n=51)	HPSD group (n=51)	P-value
Clinical characteristics			
Age	66.5±9.3	65.9±10.3	0.75
Male, n (%)	41(80)	41(80)	1
HT	28(54)	23(45)	0.32
DM	4(3)	2(1)	0.39
CHF, n (%)	27(62)	16(37)	0.01
Cerebral infarction, n (%)	4(3)	0	0.11
Paroxysmal AF, n (%)	20(39)	20(39)	1
Echocardiographic data			
Left atrial diameter (mm)	40.9±5.6	39.8±6.3	0.34
LVEF (%)	53.1±14.7	56.9±10.6	0.14
Medication			
Anti-arrhythmia drags, n (%)			
Class I, n (%)	2(3)	8(15)	0.09
Class Ⅱ, n (%)	23(45)	19(37)	0.54
Class Ⅲ, n (%)	1(1)	0	1
Class Ⅳ, n (%)	3(5)	5(9)	0.71
Laboratory data			
BNP (pg/ml)	146.1±201.4	103.1±127.1	0.2
eGFR (ml/min/1.73m²)	76.3±72.5	67.3±15.8	0.38

Continuous variables are shown as mean (±SD) and categorical variables as number (%)

Abbreviations: HT: Hypertension; DM: Diabetes Mellitus; CHF: Congestive Heart Failure; AF: Atrial Fibrillation; LVEF: Left Ventricular Ejection Fraction; LPLD: Lower-Power Long Duration; HPSD: High-Power Short Duration; BNP: Brain Natriuretic Peptide; eGFR: Estimated Glomerular Filtration Rate.

Table 2: SVC ablation.

	LPLD group (n=51)	HPSD group (n=51)	P-value
RF duration (total), s	220.4±59	79.0± 23	<0.001
Number of RF applications, n			
Total	16.8±3.6	15.6±4.4	0.15
Lateral segment	6.4±1.5	5.4±1.6	0.001
Non-lateral segment	11.4±2.1	10.3±2.2	0.01
Procedure time, min	7.3±3.8	3.9±2.3	<0.001
First pass isolation rate, %	90.2	90.2	1

Continuous variables are shown as mean (± SD) and categorical variables as number (%).

Abbreviations: SVC: superior Vena Cava; RF: Radiofrequency; LPLD: Lower-Power Long Duration; HPSD: High-Power Short Duration.

Table 3: SVC ablation lesions.

	LPLD group	HPSD group	P-value
Entire SVC segment (n=1674)			
Average CF, g	10.4±4.1	8.7±2.9	<.001
RF duration, s	12.3±3.2	4.0±0.4	<.001
AI, AU	285±24	275±28	<.001
Local impedance drop, Ω	9.7±5.4	14.9±7.8	<.001
Lateral segment (n=587)			
Average CF, g	9.5±4.0	8.3±2.6	<.001
RF duration, s	10.0±1.9	4.0±0.4	<.001
AI, AU	259±16	274±19	<.001
Local impedance drop, Ω	9.0±4.7	15.0±7.5	<.001
Septal segment (n=1087)			
Average CF, g	10.9±0.1	8.9±0.1	<.001
RF duration, s	13.4±0.1	4.0±0.1	<.001
AI, AU	297±17	275±32	<.001
Local impedance drop, Ω	10.0±0.2	14.8±0.3	<.001
Number of ablations capturing the phrenic nerves, n	8	64	<.001

Continuous variables are shown as mean (± SD) and categorical variables as number (%)

Abbreviations: SVC: Superior Vena Cava; CF: Contact Force; RF: Radiofrequency; AI: Ablation Index; LPLD: Lower-Power Long Duration; HPSD: High-Power Short Duration

Discussion

Major findings

To our knowledge, this study represents the first investigationof SVCI outcomes utilizing HPSD ablation at a setting of 50 W for 4 s. The key resultswere as follows. First, HPSD reduced operative and ablation times comparedwith LPLD, with similarly high first-pass SVC isolation rates (>90%). Second, while the site of phrenic nerve capture was significantly more ablated in the HPSD group, no increase in PNI was observed. Third, the reduction in local impedance was markedly lower in the LPLD group than that in the HPSD group. Fourth, the AF recurrence ratesat 12 months did not differ significantly, while the rate of SVC recurrence was similar, between the two groups.

SVC isolation in HPSD

The reported average ablation times for SVC ablation is 7.8 min for RF and 36.9 s for cryoballoon ablation [10]. The duration of ablation in this study exceeded that of cryoballoon ablation but was notably shorter than that of conventional RF ablation, potentially contributing to the decreased overall procedure time.

Conventional SVC ablation involves the application of energy (20–30 W for 20–30 s). Borne et al. showed comparable ablation lesion volumes between 50 W for 5 s and 20 W for 30 s and deeper lesions at 20 Win an in vivo model [11]. The reported atrial myocardium thickness within the SVC is 1.2±1.0 mm, with a maximum thickness of 4 mm [12]. In an in vivo model, the lesion depth following 50 W for 5 s with 10 g of CF was 2.3±0.5 mm [13]. Therefore, an ablation setting of 50 W for 4 s appears to be sufficient for SVC isolation. HPSD is reportedly associated with steeper and greater impedance reduction than is moderate-power moderate-duration left atrial ablation [14], comparable to the results in the present study. HPSD creates a shallower and wider lesion than does LPLD, which may affect the myocardium and increase local impedance drop. Prolonged application time and high CF in HPSD increase the risk of steam pop.

PNI in SVC isolation

The PNI rates were comparable between HSPD and LPLD. Because the HPSD group created wider and shallower lesions, PNI did not increase, despite the higher number of ablation points and AI in the lateral segment compared with the conventional setting. HPSD does not allow for deep ablation lesions due to the short ablation time. Moreover, transient PNI would have been a reversible change even if it had occurred. Pulse Field Ablation (PFA) is reportedly highly tissue selective and does not affect the phrenic nerves [15]. Reports have documented effective isolation of the SVC using PFA in patients experiencing paroxysmal AF [16]. Therefore, PFA may be applied to isolate the SVC without causing PNI.

Durability of SVC isolation in HPSD

Miyazaki et al. reported that the rate of electrical reconduction for the SVC following the initial ablation could be as high as 74%. The most likely site of reconduction is the anterolateral wall, which is closely associated with the sinus node [17]. Kawano et al. noted that 12.6% cases required touchup ablation on the anterior wall, while 7.8% needed it on the lateral wall [18]. In the anterolateral wall, concerns about sinus node dysfunction, phrenic nerve injury, and SVC stenosis often lead operators to unintentionally down grade the ablation energy to reduce risk, which may result in inadequate ablation. The SVC recurrence rate in the present study was only 33% in the HPSD group, as this strategy allowed for excessive or in sufficient ablation without increased complications. Thus, HPSD is likely to maintain the durability of ablation in both the acute and chronic phases.

Clinical implications

HPSD provides shallow and wide ablation, which is particularly useful for SVC with thin myocardium and is considered to cause less damage to the adjacent sinus node and phrenic nerves. However, the impedance drop is greater than that for conventional ablation, and care is required regarding the CF and ablation time.

Limitations

This study has several limitations. First, this was a retrospective, non-randomized, single-center study with a relatively small number of patients; thus, selection bias and time-dependent biases were possible, which could have influenced the study results. Second, follow-up studies using 12-lead electrocardiograms and 24-hour Holter monitoring, may underestimate the recurrence of atrial fibrillation, especially in asymptomatic or intermittent episodes of atrial fibrillation. Third, brief asymptomatic episodes of AF during follow-up may have resulted in an underestimation ofthe AF recurrence rate. Finally, the long-term results beyond oneyear are unknown.

Conclusion

In SVC isolation, HPSD ablation reduced operative and ablation times compared to those with LPLD ablation, with comparable first-pass SVC isolation rates. No steam pop, cardiac tamponade, or increase in phrenic nerve injury were observed, and the AF recurrence rates at oneyear were equivalent.

Author declarations

Conflict of interest disclosure: The authors declare no conflict of interest associated with this study.

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