Evaluation of an Optimized Workflow for the Radiofrequency Catheter Ablation of Paroxysmal Atrial Fibrillation

Luqian Cui
Shihua Cui
Jingchao Li
Haijia Yu
Huihui Song
Yingjie Chu
Shujuan Dong

Corresponding Author: Shujuan Dong, e-mail: hnsydsj@163.com
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Background: A significant number of atrial fibrillation (AF) recurrences occur after initial ablation, often due to pulmonary vein reconnections or triggers from non-pulmonary veins.

Material/Methods: Patients with paroxysmal AF who underwent radiofrequency catheter ablation for the first time were enrolled. Base on propensity score matching (1:1 matching), 118 patients were selected for an optimized workflow for the radiofrequency catheter ablation of paroxysmal AF (OWCA) group and a conventional group. Comparative analysis of the acute and 12-month clinical outcomes was conducted. Moreover, an artificial intelligence analytics platform was used to evaluate the quality of pulmonary vein isolation (PVI) circles.

Results: PVI was successfully achieved in all patients. Incidence of first-pass isolation of bilateral PVI circles was higher ($P=0.009$) and acute pulmonary vein reconnections was lower ($P=0.027$) in the OWCA group than conventional group. The OWCA group displayed a significant reduction in the number of fractured points ($P<0.001$), stacked points ($P=0.003$), and a greater proportion of cases in which the radiofrequency index achieved the target value ($P<0.001$). Additionally, the contact force consistently met the force over time criteria ($P<0.001$) for bilateral PVI circles in the OWCA group, accompanied by a shorter operation time ($P=0.017$). During the 12-month follow-up period, the OWCA group exhibited a higher atrial arrhythmia-free survival rate following the initial ablation procedure than did the conventional group.

Conclusions: The optimized workflow for radiofrequency catheter ablation of paroxysmal AF could play a crucial role in creating higher quality PVI circles. This improvement is reflected in a significantly elevated 12-month atrial arrhythmia-free survival rate.

Keywords: Atrial Fibrillation • Catheter Ablation

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Study Protocol

This study enrolled patients with paroxysmal AF who underwent RFCA for the first time between January 2019 and November 2021. Inclusion criteria were as follows: (1) RFCA performed for the first time; and (2) palpitation, chest tightness, and other symptoms that could not be controlled by antiarrhythmic drugs. Exclusion criteria were as follows: (1) thrombosis in the left atrium; (2) abnormal thyroid function; and (3) severe valvular heart disease or postoperative prosthetic valve surgery. Patients who adhered to the optimized workflow were defined as the OWCA group, and patients who followed the conventional workflow were designated as the conventional group. All procedures were performed by the same experienced operator. Propensity score matching of 1: 1 using age, sex, AF duration, CHA2DS2-VASc score, and left atrium diameter was conducted to control for selection bias, within a caliper of 0.05 on the propensity score.

Trial Procedures

Workflow of OWCA Group

Prior to the administration of anesthesia, all patients were connected to an automated external defibrillator to facilitate the conversion of AF to sinus rhythm. General anesthesia was subsequently administered by anesthesiologists to all patients. To aid in catheter and needle placement during the transseptal puncture procedure, an intracardiac echocardiography catheter (Soundstar; Biosense Webster, Irvine, CA, USA) was inserted into the right atrium. This catheter also served the purpose of monitoring the pericardial space in the event of a drop in oxygen saturation or arterial pressure during the procedure. A steerable decapolar catheter (DecaNAV; Biosense) was used to construct the matrix and was advanced into the coronary sinus.

Two transseptal punctures were meticulously performed at the optimal location on the interatrial septum using a Swartz sheath (Abbott, Chicago, IL, USA) and steerable sheath (VIZIGO; Biosense), respectively. These procedures were performed under X-ray and intracardiac echocardiographic guidance. After the first transseptal puncture, heparin was given at a dose of 100 U/kg body weight, with subsequent doses given to maintain the activated clotting time between 300 and 350 s. Next, electroanatomical maps of PVs and the left atrium were reconstructed using a multi-electrode mapping catheter (Pentaray; Biosense Webster, Irvine, CA, USA) was inserted into the left atrium. This catheter was used for the localization and ablation of the antrum ostium of the PVs, with the Swartz sheath serving as the conduit for its placement. Meanwhile, the mapping catheter remained positioned within the PVs to monitor the variation of potentials during the ablation process. In addition, an electrophysiological examination was carried out in the SVC. If potential was detected, SVC was performed at the level of the right pulmonary vein isolation (PVI) circle roofline after locating the phrenic nerve by high-output pacing (10 mA) on the lateral wall (Figure 1).

The radiofrequency energy was delivered by an ablation index-guided high-power ablation strategy of 50 W (irrigation flow 15 mL/min). For PVI, the target ablation index value was set at 450 to 500, with 10 to 15 g of contact force for anterior walls, and at 350 to 450, with 5 to 10 g of contact force.
for posterior walls. Ablation index values of 300 to 350, with 5 to 10 g of contact force, were applied on the lateral wall of the SVC, while 350 to 400 with similar contact force were applied on the non-lateral wall. Predefined VisiTag (Biosense) settings (the lesion-tag size 2 mm, interlesion distance 4 mm, minimum time 3 s) were used to automatically display radiofrequency applications.

**Workflow of the Conventional Group**

The procedure was performed under conscious sedation. A multipolar catheter (Biosense) was placed into the coronary sinus via the jugular or subclavian vein. A single transseptal puncture was performed using a Swartz sheath under X-ray guidance. Heparin was given to maintain activated clotting time of 300 to 350 s. The mapping of left atrium and PVs was done using a Pentaray catheter and PVI was performed using a 6 porous irrigated-tip contact force sensing catheter (ThermoCool SmartTouch; Biosense) through the Swartz sheath. Additional SVC1 was performed only when SVC-triggered AF was observed during the procedure. The delivery power was set to 35 W under the predefined VisiTag settings (with a lesion-tag size of 2 mm, interlesion distance of 6 mm, minimum time of 3 s). The specific ablation index and contact force values for each lesion chosen were left to the discretion of the catheter operator.

The immediate endpoint of our study was the absence or dissociation of potential from PVs and SVC and bilateral conduction block. In cases in which these endpoints were not met, we promptly conducted touch-up ablations at the earliest activation site. No liner ablation was performed unless a related atrial arrhythmia occurred. After a waiting period of more than 20 min, repeat electrophysiological examinations were performed using the Pentaray catheter during sinus rhythm, and pacing was performed along lesions to identify acute reconnections of PVs and SVC. If reconnections were identified, touch-up ablations were further performed. The ablation endpoint was bidirectional block and absence or dissociation of potential from PVs or SVC until the end of the procedure.

Acute effectiveness outcomes were defined as the first-pass isolation of bilateral PVI circles and the absence of acute PVRs. We also recorded the total procedural time, total operation time, and fluoroscopy time as relevant metrics. To evaluate the continuity and efficacy of PVI circles, case data about the performance of PVIs from CARTO was subjected to an artificial intelligence analytics platform. In this platform, the ablation index, contact force, delivery time, and location of every lesion tag were recorded and analyzed. We assessed the interlesion tag distances to identify fractured points, stacked points, and gaps. Fractured points were defined as lesion tags within a distance.
of ≤3 mm from any 4 points. Stacked points were characterized as lesion tags numbering ≥6 within a 6 mm radius with 1 tag as the center. Gaps were defined as interlesion distances ≥6 mm. We also examined whether the radiofrequency index reached the target ablation index value and whether contact force met the force over time (FOT) criteria, represented through graphical illustrations. FOT was specifically defined as the duration during which practical contact force reached the target contact force and accounted for more than 40% of the delivery time. Furthermore, we integrated the operation time for performing bilateral PVI circles into our assessment to evaluate procedural efficiency. To assess the quality of PVI circles, we considered the parameters of fractured points, stacked points, and gaps, as well as the proportion of radiofrequency index reaching the target value and contact force meeting the FOT criteria.

Follow-Up

Patients were scheduled for follow-up at 1 and 3 months and every 3 months thereafter, or whenever there were signs of arrhythmia. A 12-lead electrocardiogram and 24-h Holter monitoring were conducted at each visit. After a 3-month blanking period, any symptomatic or asymptomatic atrial arrhythmia lasting longer than 30 s was considered as an AF recurrence.

Statistical Analysis

All statistical analyses were conducted using the RStudio software (RStudio, Boston, MA, USA) and SPSS v25.0 software (IBM Corp, Armonk, NY, USA). Propensity score matching was used to minimize potential confounding bias when selecting cases. Continuous variables are presented as the mean±the standard deviation (SD) for normally distributed variables and were compared using the t test. For skewed distribution measurement data, we used median (Q1, Q3) and compared them using the Mann-Whitney U test. Meanwhile, categorical variables were assessed using the chi-square test. During the 12-month follow-up, the difference in atrial arrhythmia-free survival between the 2 groups was evaluated using Kaplan-Meier analysis, with 95% confidence intervals. A P value <0.05 was considered statistically significant.

Results

Patient Characteristics

The patient characteristics of each group are shown in Table 1. The baseline characteristics were not significantly different between the 2 groups.

Procedural Outcomes

As shown in Table 2, PVI was achieved in all cases. There were no statistically significant differences between the 2 groups in terms of the total procedural time, total operation time, and fluoroscopic time. In contrast, the incidence of first-pass isolation of bilateral PVI circles was higher (94.9% vs 73.6%, P=0.009), while the incidence of the acute PVR was lower (5.1% vs 20.3%, P=0.027) in the OWCA group than in the conventional group.

Table 1. Baseline clinical characteristics of the 2 groups.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>OWCA group (n=59)</th>
<th>Conventional group (n=59)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>60.6±9.6</td>
<td>62.0±11.0</td>
<td>0.369</td>
</tr>
<tr>
<td>Sex: Female</td>
<td>16 (27.1%)</td>
<td>18 (30.5%)</td>
<td>0.684</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>25.3±2.9</td>
<td>25.2±4.2</td>
<td>0.951</td>
</tr>
<tr>
<td>AF duration (y)</td>
<td>5.0 (3.0, 6.0)</td>
<td>4.0 (2.0, 7.0)</td>
<td>0.896</td>
</tr>
<tr>
<td>Congestive heart failure</td>
<td>7 (11.8%)</td>
<td>8 (13.6%)</td>
<td>0.782</td>
</tr>
<tr>
<td>Hypertension</td>
<td>22 (37.3%)</td>
<td>20 (33.9%)</td>
<td>0.701</td>
</tr>
<tr>
<td>Diabetes</td>
<td>6 (10.2%)</td>
<td>7 (11.9%)</td>
<td>0.769</td>
</tr>
<tr>
<td>Stroke</td>
<td>4 (6.8%)</td>
<td>4 (6.8%)</td>
<td>1.000</td>
</tr>
<tr>
<td>Vascular disease</td>
<td>7 (11.8%)</td>
<td>7 (11.8%)</td>
<td>1.000</td>
</tr>
<tr>
<td>CHA2DS2-VASc score</td>
<td>1.0 (0.0, 2.0)</td>
<td>2.0 (1.0, 3.0)</td>
<td>0.414</td>
</tr>
<tr>
<td>LAD (mm)</td>
<td>41.1±4.7</td>
<td>40.4±4.9</td>
<td>0.215</td>
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<tr>
<td>LVEF (%)</td>
<td>63.5±5.4</td>
<td>63.8±4.6</td>
<td>0.256</td>
</tr>
</tbody>
</table>

OWCA – optimal workflow for radiofrequency catheter ablation of paroxysmal atrial fibrillation; AF – atrial fibrillation; CHA2DS2-VASc – congestive heart failure, hypertension, age ≥75 years, diabetes mellitus, stroke/transient ischemic attack/thromboembolism, vascular disease, age 65 to 74 years, sex category; LAD – left atrial diameter; LVEF – left ventricular ejection fraction.

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Artificial Intelligence Analytics Platform Outcomes

A representative case illustrating the outcomes of PVI circles evaluated by artificial intelligence analytics platform is shown in Figure 2. The outcomes of the artificial intelligence analytics platform between the 2 groups are summarized in Figure 3. There were significantly fewer fractured points (6.8% vs 37.3%, \( P<0.001 \)), and stacked points (3.4% vs 23.7%, \( P=0.003 \)) in the OWCA group than in the conventional group. There was no gap in the OWCA group, while 3 gaps were observed in the conventional group. Additionally, the OWCA group demonstrated a higher proportion of radiofrequency index reaching the target value (96.6% vs 76.3%, \( P=0.003 \)) and contact force meeting FOT (91.5% vs 52.5%, \( P<0.001 \)) than did the conventional group. Furthermore, the OWCA group achieved significantly shorter operation times (42.4±6.1 vs 57.2±8.8, \( P=0.017 \)) during bilateral PVI circle procedures.

Follow-Up

All patients underwent a minimum of 12 months of follow-up after the initial procedure. In the OWCA group, 2 patients experienced AF recurrence, detected by Holter monitoring. Notably, 1 patient had pulmonary vein reconnection, which was observed during a secondary ablation procedure. In the Conventional group, 9 patients experienced recurrences, including 1 case of atrial tachycardia and 8 cases of AF. A secondary ablation was performed in 4 patients, and all exhibited reconnections of PVI. Kaplan-Meier curves analysis revealed that the atrial arrhythmia-free survival rate was higher in the OWCA group than in the conventional group (Figure 4, log-rank test, \( P=0.015 \)).

Complications

Both cohorts experienced a low rate of complications, with no significant difference (5.1% vs 1.7%, \( P=0.611 \)), including no occurrence of stroke, atrioesophageal fistula, or death. In the OWCA group, 3 patients reported complications, including 1 case each of pericardial effusion, hematoma, and pseudoaneurysm. Additionally, a hematoma occurred in 1 patient from the conventional group.

Discussion

Our study introduced a standard optimized workflow for the RFCA of paroxysmal AF (OWCA), contributing to the generation of higher quality PVI. This translated to a higher first-pass isolation rate and lower incidence of acute PVR and 12-month AF recurrence, without increasing the incidence of complications. Importantly, these results align with the theory that contiguous and transmural lesions, akin to surgical outcomes, are crucial for achieving long-term arrhythmia-free survival after the initial AF ablation.

There are 2 main concerns regarding the efficacy and safety of RFCA for AF. Experience has shown that achieving satisfactory clinical outcomes relies on advancements in techniques and technologies. General anesthesia offers several potential advantages, such as increased patient comfort, enhanced catheter stability, and improved lesion formation due to reduced patient movement, all of which have been demonstrated to enhance AF ablation results [18,19]. The use of a visualized steerable sheath (Vizigo) can improve catheter stability and tissue contact, can reduce procedure time and fluoroscopy, and has been shown to improve lesion formation and enhance single-procedure arrhythmia-free survival [20-23]. Moreover, ablation index-guided high-power ablation strategy amalgamated the benefits of high-power ablation and ablation index-guided ablation, enhancing the efficiency and safety of the ablation procedure [10,11,24]. In the PRAISE study, the use of ablation index-guided PVI appeared to contribute to durable PVI [25]. Higher-power ablation was chosen in the present study since it has been proven to be more effective.
Intracardiac echocardiography was used as another catheter to visualize ablation sites and promptly identify periprocedural complications, a technique that has been proven to reduce procedure-related complications [14,15]. SVC can play a significant role in triggering and maintaining AF in non-PV foci. Empirical SVC, in addition to PVI, has been demonstrated to further reduce AF recurrences [26,27]. Herein, we streamlined those advancements to improve single-procedure arrhythmia-free survival and to make them accessible for adoption and replication by different operators.

Figure 2. Representative case evaluated by an artificial intelligence analytics platform. (A) The original VisiTag diagram. (B) No fractured points (black arrow), stacked points, and gaps in bilateral pulmonary vein isolation (PVI) circles. (C) The proportion of contact force (CF) meeting force over time (FOT) was 100% in bilateral PVI circles. (D) The proportion of radiofrequency (RF) index reaching the target value was 100% in bilateral PVI circles. (E) The operation time of performing bilateral PVI circles was less than 40 min.
In the OWCA workflow, we meticulously optimized every aspect of the catheter ablation process for AF, including general anesthesia, ablation index-guided high-power ablation strategy, and use of visualized steerable sheaths and intracardiac echocardiography, striving to enhance catheter operability and stability to generate continuous and transmural lesions akin to surgical intervention. The quality of PVI circles was evaluated by a novel artificial intelligence analytics platform, revealing a significant reduction in the number of fractured points and stacked points without gaps in the OWCA group. The fractured points and stacked points referred to multiple lesion tags on very small scales, which increased the chances of potentially reversible edema. Gaps in the ablation circles are one of the main reasons for PVR [28]. The reduced occurrence of fractured points and stacked points without gaps on PVI circles translated into a higher likelihood of achieving first-pass isolation and a decreased probability of encountering acute and late reconnections. Furthermore, it was demonstrated that the

Figure 3. Comparison between the optimal workflow for radiofrequency catheter ablation of paroxysmal atrial fibrillation (OWCA) group and the conventional group in terms of fractured points, stacked points, gaps, the proportion of radiofrequency (RF) index reaching the target value, contact force meeting force over time (FOT), and operation time.
The ablation index could reach the target value, and it was easier for the contact force to meet the criterion of FOT in the OWCA group. This contributed to creating transmural and durable lesions by delivering enough energy, leading to a higher first-pass isolation rate and reducing the incidence of PVI reconnections [29,30]. The reduced duration of the procedure required for performing bilateral PVI circles in the OWCA group underscored the heightened procedural efficiency, compared with that of the conventional group. Collectively, these observations indicated that the OWCA workflow enabled the creation of higher quality PVI circles. More importantly, the superior results obtained from these parameters indirectly underscore the enhanced operability and stability of catheters within the optimized workflow. These aspects are of paramount importance for cardiac electrophysiologists, particularly for those who may be less experienced, as they contribute significantly to the reproducibility of this approach [31].

**Study Limitations**

This study had several limitations, including the small sample size from a single center. Also, patients following the optimized workflow were compared to a matched control group in a non-randomized manner. To establish the safety and effectiveness of OWCA, involving general anesthesia, ablation index-guided high-power ablation strategy, visualized steerable sheaths, intracardiac echocardiography, and additional SCVI, had demonstrated effectiveness in producing higher quality PVI circles and improving acute and 12-month clinical outcomes.

**Conclusions**

OWCA, involving general anesthesia, ablation index-guided high-power ablation strategy, visualized steerable sheaths, intracardiac echocardiography, and additional SCVI, had demonstrated effectiveness in producing higher quality PVI circles and improving acute and 12-month clinical outcomes.

**Acknowledgments**

We extend our gratitude to all participants in this study for their scientific contributions.

**Ethics Statement**

The study was approved by the Ethics Committee of Henan Provincial People’s Hospital and was conducted in accordance with the Helsinki Declaration.
Declaration of Figures’ Authenticity

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References:


