Counterclockwise Heart Rotation Affects Variation in Successful Ablation Line Position in Common Atrial Flutter

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Background: Linear ablation of atrial flutter usually targets a 6 o'clock position on the cavotricuspid isthmus on left anterior oblique view, but the difficulty of the ablation often requires a variation in successful ablation line position from 5 to 7 o'clock.

Methods and Results: This study included 94 patients without structural heart disease. A linear lesion was created in turn at the 6, 7, and 5 o'clock positions until bidirectional block of the isthmus was completed; the final lesion was defined as the successful ablation line. The degree of counterclockwise heart rotation (CCW-HR) was evaluated in a blinded fashion according to the angle between the vertical line crossing the His bundle catheter and the line connecting the His bundle catheter and coronary sinus ostium. Successful ablation lines were obtained at the 6 o'clock position in 59 patients (63%); the 7 o'clock position in 19 patients (20%; the oldest group with a moderate radiofrequency burden); and the 5 o'clock position in the remaining 16 (17%; the youngest group with the largest radiofrequency burden). Age-related increase in CCW-HR was the only independent predictor of a more septal successful ablation line (OR, 7.1; 95% CI: 3.3–14.3; P<0.01).

Conclusions: Variation in successful ablation line position was affected by age-related CCW-HR; its evaluation might reduce radiofrequency burden, especially in the young and elderly. (Circ J 2014; 78: 859–864)

Key Words: Atrial flutter; Catheter ablation; Heart rotation

Catheter ablation has become well established as a curative treatment for typical atrial flutter (AFL).\textsuperscript{1–3} A successful AFL ablation is achieved by creating a linear lesion with bidirectional conduction block in the cavotricuspid isthmus (CTI). The central part of the CTI (central CTI) is a reasonable site for creating the linear lesion, because it has a shorter length and thinner myocardium.\textsuperscript{4,5} Therefore, AFL ablation targets the central CTI, which is speculated to be at a 6 o'clock position on left anterior oblique (LAO) view. The linear lesion for successful AFL ablation, however, varies from a 5 to 7 o'clock position on LAO view. Although previous studies have reported several predictors of successful AFL ablation, they have not sufficiently investigated the variation in successful AFL ablation line position.\textsuperscript{6–8} The aim of this study was to clarify the factors affecting variation in successful AFL ablation line position.

Methods

Subjects

This study included 94 consecutive patients (80 men; mean age, 58±11 years; range, 24–83 years) without any structural heart disease who underwent AFL ablation at Tsukuba University Hospital. Prophylactic AFL ablation was performed during ablation of atrial fibrillation in 84 patients without any clinical AFL, and curative AFL ablation was performed in the remaining 10 patients with clinical AFL. Ethics approval was obtained from the institutional review committee, and all patients gave their informed, written consent before participation.

AFL Ablation Procedure

The AFL ablation was performed with an 8-mm-tip, quadrupolar, deflectable, 2-5-2 inter-electrode-spaced and temperature-controlled ablation catheter (Ablaze, single directional E curve, Japan Life Line) supported by a long guiding introducer (SL0, St. Jude Medical). To create linear lesions, radiofrequency (RF)
energy was delivered sequentially to the CTI from 1 point to the next (point by point) where the atrial potential was ≥0.1 mV. The duration of a single RF application was up to 60 s with a maximum power of 50 W and maximum temperature of 60°C. The total amount and number of RF energy applications were assessed. The total procedure time, defined as the time from the start of the first RF energy application to the end of the last RF energy application at the isthmus, was also measured. To avoid any model bias of the ablation catheter in ablation outcome, only 1 ablation catheter model type was used in this study.

The AFL ablation line was selected in turn in the standard fashion. The first ablation line was created at the 6 o’clock position on 45° LAO view. If that was unsuccessful, a new ablation line was created at the 7 o’clock position on 45° LAO view. If that also was ineffective, the 5 o’clock position on 45° LAO view was then targeted. To minimize the effects of operator experience, catheter ablation was performed by 2 physicians (H.T.; Y.S.) who had carried out >200 catheter ablations for AFL. Before moving the ablation line to a new site, the atrial potential was calibrated with a 50 mm lead sphere.

The distance from the His position to the roof of the CS ostium (HC distance) was measured in both the 45° LAO view and 35° right anterior oblique (RAO) view. The CTI length was defined as the distance from the tricuspid annulus where the atrial potentials appeared (≥0.1 mV) to the inferior vena cava where the atrial potentials disappeared (<0.1 mV) on 35° RAO view. Those measurements were calibrated with a 50 mm lead sphere.

Statistical Analysis
Continuous variables are expressed as mean±SD and compared using analysis of variance (ANOVA) followed by Tukey post-hoc test. The categorical variables were compared using Fisher’s exact test. On ordinal logistic regression analysis, the possible predictors of a successful AFL ablation line (P<0.30 after univariate analysis) were included in the multivariate model, in which variables with P>0.2 were eliminated in a stepwise fashion. Receiver operating characteristic (ROC) analysis was performed to evaluate the predictability of CCW-HR for successful AFL ablation site. The optimal cut-off point for ROC analysis was defined as that which maximized the sum of the sensitivity and specificity. The correlation coefficient (r) was calculated to evaluate the linear association between the CCW-HR and continuous variables of the baseline characteristics. P<0.05 was considered significant. All statistical analysis was performed with SPSS for Windows version 20.0 (SPSS, Chicago, IL, USA).

Results
Baseline Characteristics and Successful AFL Ablation Line Position
AFL ablation was successfully performed without any complications in all patients. Successful AFL ablation line on 45° LAO view was located at the 6 o’clock position in 59 patients (63%); 6 o’clock group), 7 o’clock position in 19 patients (20%; 7 o’clock group), and 5 o’clock position in 16 patients (17%; 5 o’clock group). The baseline characteristics and procedural outcomes of AFL ablation are compared in Table 1.

The 5 o’clock group had the largest CCW-HR (64±9°), and highest age (67±8 years), and RF burden (RF energy, 62±19 kJ).
AFL Ablation and Age-Related Heart Rotation

The 6 o’clock group had a moderate CCW-HR (46±10°) and age (59±10 years) with the smallest RF burden (RF energy, 30±20kJ with 14±8 RF applications). The 7 o’clock group had the smallest CCW-HR (33±8°) and lowest age (48±12 years) with a moderate RF burden (RF energy, 46±13kJ with 24±6 RF applications). The fluoroscopic distance between the successful and 6 o’clock ablation lines on LAO view was 10.1±2.3 mm in the 7 o’clock group, and 8.4±2.2 mm in the 5 o’clock group. The echocardiographic parameters and prevalence of hypertension (HT), diabetes mellitus (DM), and hyperlipidemia (HL) did not differ between the 3 groups (Table 1).

### Predictors of Successful AFL Ablation Line Position

On multivariate ordinal logistic regression analysis, CCW-HR was the only independent predictor of successful AFL ablation line (odds ratio for a more septal successful AFL ablation line, 7.1 per 10° increase in the CCW-HR; 95% confidence interval [CI]: 3.3–14.3; P<0.001; Table 2). To identify the 5 o’clock group, the area under the ROC curve (AUC) for CCW-HR was 0.93 (95% CI: 0.86–1.00, P<0.001; Figure 2A). CCW-HR ≥60° was identified as the optimal cut-off to predict a 5 o’clock line, providing a sensitivity of 88%, specificity of 96%, negative predictive value of 96%, and positive predictive value of 81%.

To identify the 7 o’clock group, the AUC for CCW-HR was 0.89 (95% CI: 0.80–0.98, P<0.001; Figure 2B). CCW-HR <38°

### Table 1. Baseline Subject Characteristics

| Variables                        | 5 o’clock (n=16) | 6 o’clock (n=59) | 7 o’clock (n=19) | F2,91 | P-value |
|----------------------------------|-----------------|-----------------|-----------------|-------|---------|
| Age (years)                      | 67±8            | 59±10           | 48±12           | 15.44 | <0.001*†‡ |
| Men                              | 13 (81)         | 52 (88)         | 15 (79)         | 0.500 |
| Height (cm)                      | 163±7           | 168±8           | 166±9           | 2.67  | 0.075   |
| Body weight (kg)                 | 64±9            | 70±12           | 67±13           | 2.08  | 0.131   |
| Body surface area (m²)           | 1.7±0.2         | 1.8±0.2         | 1.7±0.2         | 2.62  | 0.078   |
| Body mass index (kg/m²)          | 24±2            | 25±3            | 24±3            | 0.54  | 0.583   |
| Hypertension                     | 12 (75)         | 37 (63)         | 9 (47)          | 0.261 |
| Hyperlipidemia                   | 7 (44)          | 35 (59)         | 7 (37)          | 0.185 |
| Diabetic mellitus                | 8 (50)          | 13 (22)         | 3 (16)          | 0.061 |
| LVEF (%)                         | 64±11           | 67±8            | 67±8            | 1.10  | 0.338   |
| LVEDD (%)                        | 47±6            | 48±5            | 48±3            | 0.68  | 0.510   |
| LVESD (mm)                       | 30±5            | 30±5            | 30±4            | 0.03  | 0.974   |
| Interventricular septum (mm)     | 9±2             | 10±2            | 9±3             | 0.38  | 0.685   |
| LV posterior wall (mm)            | 9±2             | 10±2            | 9±2             | 0.53  | 0.589   |
| LV mass index (g/m²)             | 85±20           | 91±25           | 88±31           | 0.33  | 0.723   |
| Left atrial diameter (mm)        | 41±7            | 39±7            | 36±7            | 1.74  | 0.182   |

### Table 2. Predictors of Successful AFL Ablation Line Position

| Risk factors                     | OR (95% CI)     | P-value |
|----------------------------------|-----------------|---------|
| CCW-HR (per 10° increase)        | 7.1 (3.3–14.3)  | <0.001  |
| Age (per decade increase)        | 1.6 (0.9–2.7)   | 0.114   |
| Hypertension                     | 2.8 (0.8–9.1)   | 0.098   |

Data given as mean±SD or n (%). P<0.05 (Tukey post-hoc test following ANOVA): *(5 vs. 6 o’clock group), †(6 vs. 7 o’clock group), ‡(7 vs. 5 o’clock group).

CCW-HR, angle between the vertical line crossing the His bundle catheter and line connecting the His position and roof of the coronary sinus ostium; CTI length, length of the cavotricuspid isthmus; HC distance, distance from the His position to the roof of the coronary sinus ostium; LAO, left anterior oblique; LV, left ventricle; LV posterior wall (mm); LV mass index (g/m²); RAO, right anterior oblique; RF, radiofrequency; CCW-HR, counter clockwise heart rotation; CI, confidence interval; OR, odds ratio.
Major Findings
Variation in successful AFL ablation line position on 45° LAO view was affected and predicted by CCW-HR, which positively correlated with age \( (r=0.565, P<0.001; \text{Figure 3A}) \). Examples of age-related heart rotation are shown in \textbf{Figure 3B} (70-year-old man with large CCW-HR) and \textbf{Figure 3C} (27-year-old man with small CCW-HR). CCW-HR also had a mild correlation with CTI length \( (r=0.333, P=0.001) \), but it had a poor correlation with procedure time \( (r=0.251, P=0.015) \), number of RF applications \( (r=0.230, P=0.026) \), and total RF energy \( (r=0.298, P=0.004) \).

There was no significant correlation between CCW-HR and echocardiographic parameters: left ventricular ejection fraction \( (r=0.033, P=0.749) \), left ventricular end-diastolic dimension \( (r=-0.075, P=0.471) \), left ventricular end-systolic dimension \( (r=-0.073, P=0.485) \), interventricular septum dimension \( (r=0.063, P=0.545) \), posterior wall dimension \( (r=0.167, P=0.107) \), left ventricular mass index (LVMI; \( r=0.073, P=0.487) \), and left atrial diameter \( (r=0.155, P=0.135) \).

In addition, CCW-HR was greater in the patients with HT than in those without \( (50\pm13 vs. 41\pm11°, P<0.001) \). It was also greater in the patients with DM than in those without \( (52\pm13 vs. 45\pm13°, P=0.001) \). In contrast, it did not differ between the patients with and without HL \( (46\pm12 vs. 47\pm14°, P=0.834) \).

**Discussion**

**Mechanism of Difficulty in 6 o’clock AFL Ablation On LAO View**

The CTI varies in myocardial distribution and thickness with regard to its paraseptal, central, and inferolateral parts. The central CTI is the preferred target for AFL ablation because it is thinner along its entire length than the paraseptal and inferolateral CTI. Therefore, AFL ablation initially targets the 6 o’clock position, which corresponds with the central CTI on LAO view. A linear ablation at the 6 o’clock position, however, fails to...
AFL Ablation and Age-Related Heart Rotation

Successful AFL ablation line position, speculated to be within the central CTI, was affected and predicted by CCW-HR (Figure 2; Table 2). The mild correlation between CCW-HR and CTI length \( r=0.333, P=0.001 \) may be responsible for the longer length of the inferolateral CTI than that of the central and paraseptal CTI.\(^3\) These data suggest that the 6 o’clock position on LAO view may correspond to the paraseptal CTI in patients with smaller CCW-HR (the 5 o’clock group) and to the inferolateral CTI in patients with larger CCW-HR (the 7 o’clock group). These discrepancies between the 6 o’clock position and central CTI may cause difficulty during AFL ablation targeting the 6 o’clock position as the initial ablation line.

Age-Related Changes in the Heart

The aorta lengthens with age, due primarily to the elongation of the ascending aorta.\(^ {11} \) The age-related aortic elongation may cause an age-related CCW-HR.\(^ {10,12} \) Similar to the present results, the HC distance on RAO view is reported to decrease with age, but there is no significant correlation between H-C distance on LAO view and age.\(^ {12,13} \) In addition, the angle between the direction of the needle at the transseptal puncture site and a horizontal line on LAO view is reported to decrease with age.\(^9\) These findings might explain the mechanism of age-related CCW-HR. Beneficial use of this information, however, has been limited to catheter ablation of AVNRT and the transseptal puncture.\(^ {9,12,13} \)

Overall, the CCW-HR moderately correlated with age \( r=0.565, P<0.001 \). In the younger quartile, the only significant correlating factor of CCW-HR was the age \( r=0.469, P=0.024 \). In the older quartile, however, CCW-HR had a negative correlation with LVMI \( r=-0.405, P=0.049 \). These findings suggest that CCW-HR increases with aging due to aortic elongation, but age-related CCW-HR may be counteracted by an increase in LVMI. These mechanisms prevent the strong correlation between CCW-HR and aging, and also spoil the potential utility of aging as a predictor of optimal ablation line. Therefore, the optimal ablation line should be guided by CCW-HR (the only in-

![Figure 3](image-url)
dependent predictor of successful ablation line).

**Clinical Implications**

This study proposed that age-related CCW-HR may be worth evaluating for AFL ablation because CCW-HR affected and predicted successful AFL ablation line position (Figures 2,3; Table 2). This may be more beneficial especially in the young and elderly, who might have an inconsistency between the central CTI and the 6 o’clock position on LAO view. This inconsistency seemed to be responsible for the difficulty encountered with AFL ablation that initially targeted the 6 o’clock position. Therefore, CCW-HR should be evaluated, especially in the young and elderly when performing AFL ablation.

Bidirectional conduction block might be completed in combination with multiple ablation points for plural lines. The critical ablation point of the successful ablation line, however, would be included in the central CTI with thinner myocardium. Therefore, CCW-HR should be evaluated to detect the ablation line corresponding to the central CTI that includes the critical point.

Changing the angle of the LAO view is a possible option for matching the 6 o’clock position with the optimal ablation line in patients with inconsistency between the central CTI and 6 o’clock position. For example, in patients with a larger CCW-HR, the LAO view should be obtained more laterally in order to match the 6 o’clock position with the optimal ablation line. This causes a vertical discordance, however, between the ventricular and atrial side of the ablation line; the ventricular side will be located more laterally, whereas the atrial side will be located in a more septal position. Therefore, changing the ablation line seems to be more reasonable rather than changing the angle of the LAO view in patients with a larger CCW-HR.

**Study Limitations**

Although the prevalence and morphology of sub-Eustachian pouch may affect the success of AFL ablation, this was not evaluated in the present study. The detection of anatomic complexity such as sub-Eustachian pouch, however, requires additional imaging on either right atriotomy, cardiac computed tomography, cardiac magnetic resonance imaging, or intracardiac echocardiograms. In contrast, evaluation of CCW-HR does not require this; it is measured during the venous phase of left coronary angiography, which is usually performed to evaluate CS morphology for the safe insertion of a catheter inside the CS when performing AFL ablation.

Measurements in the oblique projection may be distorted by the lack of perfect orthogonality to the fluoroscopic plane. Adjusting the degree of the oblique projection to obtain perfect orthogonality to the fluoroscopic plane, however, may impair clinical utility given the complexity of this process. The use of a high-resolution 3-D electro-anatomical mapping system (CARTO 3) might support the present findings.

The RF burden might not have been smaller in the 6 o’clock group when the initial ablation line was created at the 5 o’clock position. The 6 o’clock position, however, in general is conventionally the initial target for CTI ablation. This study provided a practical insight into the conventional method of CTI ablation. A further study comparing variation in the initial ablation lines in a prospective fashion would strengthen the present findings.

The bipolar local atrial potential might be helpful in selecting the optimal AFL ablation line position, but the question of whether a high or low voltage should be targeted remains controversial. In addition, the difference in catheter stability, especially with respiration, might affect successful ablation line position. Quantitative evaluation of catheter stability using a novel catheter capable of sensing the contact force may solve this limitation in the future.

**Disclosures**

No author has a real or perceived conflict of interest.

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