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Extremely low-frame-rate digital fluoroscopy in catheter ablation of atrial fibrillation

A comparison of 2 versus 4 frame rate

Ji Hyun Lee, MD[a], Jun Kim, MD, PhD[a,*], Minsu Kim, MD[a], Jongmin Hwang, MD[a], You Mi Hwang, MD[a], Joon-Won Kang, MD[b], Gi-Byoung Nam, MD[a], Kee-Joon Choi, MD[a], You-Ho Kim, MD[a]

Abstract

Despite the technological advance in 3-dimensional (3D) mapping, radiation exposure during catheter ablation of atrial fibrillation (AF) continues to be a major concern in both patients and physicians. Previous studies reported substantial radiation exposure (7369–8690 cGy cm^2) during AF catheter ablation with fluoroscopic settings of 7.5 frames per second (FPS) under 3D mapping system guidance. We evaluated the efficacy and safety of a low-frame-rate fluoroscopy protocol for catheter ablation for AF.

Retrospective analysis of data on 133 patients who underwent AF catheter ablation with 3-D electro-anatomic mapping at our institute from January 2014 to May 2015 was performed. Since January 2014, fluoroscopy frame rate of 4-FPS was implemented at our institute, which was further decreased to 2-FPS in September 2014. We compared the radiation exposure quantified as dose area product (DAP) and effective dose (ED) between the 4-FPS (n=57) and 2-FPS (n=76) groups.

The 4-FPS group showed higher median DAP (599.9 cGy cm^2; interquartile range [IR], 371.4–1337.5 cGy cm^2 vs. 392.0 cGy cm^2; IR, 289.7–591.4 cGy cm^2; $P<.01$), longer median fluoroscopic time (24.4 min; IR, 17.5–34.9 min vs. 15.1 min; IR, 10.7–20.1 min; $P<.01$), and higher median ED (1.1 mSv; IR, 0.7–2.5 mSv vs. 0.7 mSv; IR, 0.6–1.1 mSv; $P<.01$) compared with the 2-FPS group. No major procedure-related complications such as cardiac tamponade were observed in either group. Over follow-up durations of 331 ± 197 days, atrial tachyarrhythmia recurred in 20 patients (35.1%) in the 4-FPS group and in 27 patients (35.5%) in the 2-FPS group ($P=.96$). Kaplan–Meier survival analysis revealed no significant different between the 2 groups (log rank, $P=.25$).

In conclusion, both the 4-FPS and 2-FPS settings were feasible and emitted a relatively low level of radiation compared with that historically reported for DAP in a conventional fluoroscopy setting.

Abbreviations: 3D = 3-dimensional, AF = atrial fibrillation, AT = atrial tachyarrhythmia, BMI = body mass index, CT = computed tomography, CTI = cavotricuspid isthmus, DAP = dose area product, DLP = dose length product, ECG = electrocardiography, ED = effective dose, FPS = frames per second, IR = interquartile range, PVI = pulmonary vein (electrical) isolation, PV = pulmonary vein, RF = radiofrequency.

Keywords: atrial fibrillation, catheter ablation, radiation, radiofrequency

1. Introduction

Radiation exposure is one of the major concerns with catheter ablation treatment of atrial fibrillation (AF). Although 3-dimensional (3D) electroanatomic mapping systems significantly reduce the procedure time and radiation exposure compared with fluoroscopic mapping,[1,2] a prolonged fluoroscopic time is often required due to the complexity of the procedure.[3] Moreover, repeated procedures may be needed afterwards to maintain normal sinus rhythm. In addition, some patients undergo computed tomography (CT) to obtain accurate anatomic information before catheter ablation.[4] Thus, substantial doses of radiation may accumulate in both patients and physicians.[5–8]

Reduction in fluoroscopic time and frame rate is the most direct way to minimize radiation exposure.[9] The use of extremely low-frame-rate digital fluoroscopy has been shown to decrease radiation exposure associated with catheter ablation of supraventricular tachycardia.[10] However, in a complex catheter ablation procedure such as that for AF, maintaining procedural safety and efficacy often require high-quality imaging support, which may not be achieved by low-frame-rate fluoroscopy. To date, the feasibility of extremely low-frame-rate fluoroscopy at a frame rate of 2 frames per second (FPS) has not been evaluated for AF catheter ablation. In this study, we evaluated the efficacy and safety of a low-frame-rate fluoroscopy protocol during catheter ablation for AF. In addition, we assessed the total radiation exposure, including that from CT imaging, in AF patients who were treated with catheter ablation.

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[a] Department of Cardiology, Asan Medical Center, University of Ulsan College of Medicine, [b] Department of Radiology, Asan Medical Center, University of Ulsan College of Medicine, Seoul, Korea.

[*] Correspondence: Jun Kim, Heart Institute, Asan Medical Center, University of Ulsan College of Medicine, 88, Olympic-Ro 43-Gil, Songpa-Gu, Seoul 05505, Korea (e-mail: mdjunkim@gmail).

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2. Subjects and methods

2.1. Study population and design

We conducted a retrospective review of medical records of patients who underwent catheter ablation for AF using CARTO 3 3D mapping system (Biosense–Webster, Baldwin Park, CA) between January 2014 and May 2015. In January 2014, the fluoroscopy rate for AF ablation procedures at our institute was changed from the conventional 7.5-FPS to 4-FPS. Subsequently, we changed the fluoroscopy rate to 2-FPS in the period between September 2014 and May 2015. AF was classified according to the Heart Rhythm Society/European Heart Rhythm Association/ European Cardiac Arrhythmia Society (HRS/EHRA/ECAS) 2012 Consensus Statement on Catheter and Surgical Ablation of AF.[11]

Primary outcomes were procedure time, fluoroscopic time (an indicator of radiation exposure), dose area product (DAP), and estimated effective dose (ED). The procedure time was defined as the time from the initiation of local anesthesia for vascular puncture to catheter removal. The fluoroscopic time and DAP were summed over the entire procedure. Secondary outcomes included radiation exposure from prior CT (dose length product [DLP] and ED), procedure-related complications, immediate procedural success, and the recurrence of atrial tachyarrhythmia (AT) during follow-up. AT included AF, atrial tachycardia, and atrial flutter. Immediate procedural success was defined as complete isolation with an entrance block of the 4 pulmonary veins (PVs). AT recurrence was defined as any documented episode of AT on a 12-lead electrocardiography (ECG) or AT that lasted >30 s as assessed by Holter monitoring, with or without the use of antiarrhythmic medications. On the basis of these guidelines, none of the episodes of AT that occurred within the first 3-month blanking period after the ablation procedure was included.[11] Outcomes were compared between patients treated at a frame rate of 4-FPS and those treated at a frame rate of 2-FPS. Patients who had previously undergone maze operation or AF ablation were excluded from the analysis to minimize selection bias related to radiation exposure and procedure time. The ethical review board at our institute approved this retrospective study, and the requirement for informed consent was waived due to its retrospective nature. The study protocol conformed to the ethical principles enshrined in the 1975 Declaration of Helsinki.

2.2. Catheter ablation

All patients received therapeutic oral anticoagulation with vitamin K antagonist or non-vitamin K oral antagonist for a minimum period of 3 weeks prior to the procedure according to the guideline.[12] The patients underwent transesophageal echocardiography to exclude left atrial thrombus. AF ablation procedure was performed under sedation induced by intravenous injection of remifentanil and dexmedetomidine. The initial diagnostic catheter placement and trans-septal puncture were performed under fluoroscopic guidance. A duo-decapolar catheter (St. Jude Medical, Saint Paul, MN) was positioned at the coronary sinus and right atrium via the femoral vein. Two 8.5Fr SL-1 sheaths (St. Jude Medical) were advanced to the left atrium via a trans-septal approach. Activated clotting time was maintained at 300 to 350 s by administration of a heparin bolus. Heparinized saline was infused to the left atrial sheaths to prevent thrombus formation. After trans-septal catheterization, 3D electroanatomic maps of the left atrium and PVs were reconstructed using a nonfluoroscopic navigation system (CARTO 3, version 2, Biosense Webster Inc., Diamond Bar, CA). Fast anatomic maps were acquired during AF or the sinus rhythm by respiratory gating using an ablation catheter or circular mapping catheter. Imaging integration with a preacquired CT image was performed depending on the operator's preference.

Radiofrequency (RF) pulses were delivered using a 3.5-mm Navistar Thermocool SF or Thermocool SmartTouch (Biosense Webster) in power control mode. RF power was set between 25 and 35 W, depending on the left atrial site; the catheter tip was irrigated with saline at a flow rate of 2 mL/min during mapping and at 17 to 30 mL/min during ablation. RF was delivered for up to 30 s to produce a circumferential lesion around the PVs at the ipsilateral antrum level. Lesions around the PVs were created by the sequential point-by-point application of RF energy. A circular duo-decapolar mapping catheter (LASSO, Biosense Webster) was used to confirm PV electrical isolation (PVI) based on the demonstration of an entrance block. Resumption of conductions between the left atrium and PVs were evaluated for 30 min after ablation. In cases of reconnection, PVs were newly isolated by targeting any residual electrical breakthrough. Additional substrate modification was performed at the discretion of the operator based on the inducibility of the tachycardia. Bidirectional blocks across the left atrial linear lesions were verified using previously established criteria.[13,14]

2.3. Fluoroscopy protocol

A monoplane image intensifier unit (Siemens, Erlangen, Germany) was used to measure real-time fluoroscopic time and DAP. A 20×20-cm detector with a 60-cm focus-skin distance along with a half-value layer of 5.7-mm-thick aluminum and an 81-kV beam was used. An anti-scatter grid and collimator were attached for fluoroscopy. The basic fluoroscopy procedure had a frame rate of either 2-FPS or 4-FPS. When high-quality images were required in situations such as trans-septal puncture (at operator's discretion), pulmonary venography, or evaluation of cardiac border movement, the frame rate was temporarily increased to ≥4-FPS. Pulmonary venography was not performed routinely; it was only conducted in the event of a discrepancy between the 3D geometry and fluoroscopic images. To avoid unnecessary radiation exposure, the collimation window was frequently adjusted by the operator throughout the procedure. The example video of 2-FPS and 4-FPS setting during trans-septal puncture was presented in a movie file (see Video, Supplemental Digital Content 1, http://links.lww.com/MD/B742—comparison of the real-time frame rates between 2-FPS and 4-FPS during trans-septal catheterization).

2.4. CT protocol

An ECG-gated second-generation dual-source cardiac CT (Somatom Definition Flash, Siemens) was used at our institute.[15] The tube voltage and tube current-time product were adjusted according to the patient body size; the scan parameters were as follows: tube voltage, 100 to 120 kV; tube current-time product, 240 to 360 mAs; collimation, 128×0.6 mm; gantry rotation time, 280 s; and temporal resolution, 75 ms. A bolus of 70 to 90 mL of contrast agent was administered at the rate of 4.0 mL/s, followed by 40 mL of saline chaser. A retrospective ECG-gated spiral scan was performed and ECG-based tube current modulation was applied to decrease the radiation dose. The scan range spanned from the aortic arch to the heart base and covered the entire heart and PVs. CT data were transferred to an external workstation (Syngo, Siemens) for postprocessing.

2.5. Calculation of the ED

ED, a weighted sum of organ doses, is used to estimate the stochastic risk of radiation exposure in patients undergoing

Table 1

Baseline characteristics of the study population according to the fluoroscopy rate.

	4-FPS (n=57)	2-FPS (n=76)	P
Age, y	58.1±10.6	57.8±10.5	.87
Male	43 (75.4)	55 (72.4)	.69
BMI, kg/m^2	24.8±2.7	26.2±3.1	.01
Persistent AF	12 (21.1)	22 (28.9)	.30
History			
CHF	7 (12.3)	4 (5.3)	.15
Hypertension	19 (33.3)	20 (26.3)	.38
Diabetes	5 (8.8)	6 (7.9)	.86
Stroke	7 (12.3)	4 (5.3)	.15
Vascular disease	6 (10.5)	3 (3.9)	.14
CHADS2	1.1±1.2	0.8±1.0	.07
CHADS2VASc	1.5±1.4	1.1±1.1	.08
CHADS2VASc (≥2)	22 (38.6)	20 (26.3)	.13
LVEF, %	59.4±8.0	58.4±7.9	.47
LA size, mm	40.6±5.6	42.9±7.0	.03
E/E′	11.0±4.5	10.8±6.8	.87

Values are expressed as means±standard deviation or n (%).
AF=atrial fibrillation, BMI=body mass index, CHF=congestive heart failure, FPS=frames per second, LA=left atrium, LVEF=left ventricular ejection fraction.

Table 2

Procedural outcomes and radiation exposure according to the fluoroscopy rate.

	4-FPS (n=57)	2-FPS (n=76)	P
4 PVI success	57 (100.0)	76 (100)	NA
4 PVI+LA linear ablation	19 (33.3)	34 (44.7)	.18
Procedural time, min	275.0 (245.0–313.0)	229.0 (185.0–278.0)	<.01
Fluoroscopy time, min	24.4 (17.5–34.9)	15.1 (10.7–20.1)	<.01
DAP, cGy cm^2	599.9 (371.4–1337.5)	392.0 (289.7–591.4)	<.01
ED estimate, mSv	1.1 (0.7–2.5)	0.7 (0.6–1.1)	<.01

Values are expressed as n (%), means±standard deviation, or medians (interquartile range).
DAP=dose area product, ED=effective dose, FPS=frames per second, LA=left atrium, NA=not applicable, PVI=pulmonary vein isolation.

interventional procedures.[16] On the basis of previous studies, fluoroscopic ED was calculated from DAP using previously established dose conversion coefficients.[16,17] The conversion coefficients were 0.218 mSv/Gy cm^2 for patients of a normal weight (body mass index [BMI], 18.5–24.9 kg/m^2), 0.180 mSv/Gy cm^2 for overweight patients (BMI, 25–30 kg/m^2), and 0.154 mSv/Gy cm^2 for obese patients (BMI, >30 kg/m^2). ED from cardiac CT was calculated on the basis of DLP. To calculate the ED, the DLP was multiplied by the appropriate conversion coefficient (k) for the chest, as recommended by the European Working Group for Guidelines on Quality Criteria in CT; the conversion coefficient was 0.014 mSv/mGy cm.[18]

2.6. Statistical analysis

As this was a retrospective exploratory study, a sample size calculation was not performed. Data on continuous variables are presented as mean±standard deviation or median (interquartile range [IR]). Variables with normal distribution were compared using Student *t* test; those with skewed distribution were compared using Mann–Whitney *U* test. Categorical variables are presented as frequencies (percentage), and between-group differences assessed by chi-squared test. *P* values of <.05 were considered indicative of a statistically significant between-group difference. A univariable linear regression model was used for the prediction of DAP. Variables of FPS, BMI, and fluoroscopic time were assessed for the prediction of DAP. Kaplan–Meier survival analysis was used to compare the recurrence of AT between 2-FPS and 4-FPS groups. All analyses were performed using SPSS, version 20 software package (SPSS Inc., Chicago, IL) and MedCalc Software version 11.6 (MedCalc Inc., Ostend, Belgium).

3. Results

3.1. Baseline patient characteristics

A total of 154 patients underwent AF ablation with 3D mapping at our hospital during the study reference period. We excluded 13 patients who had undergone a previous maze operation and 8 who had undergone AF ablation treatment. Finally, data from 133 patients (4-FPS group, n=57; 2-FPS group, n=76) were included in the analysis.

Patients in the 4-FPS group had lower BMI (24.8 kg/m^2 vs. 26.2 kg/m^2, *P*=.01) and smaller left atrial size (40.6 mm vs. 42.9 mm in the 2-FPS group, *P*=.03) compared to those in the 2-FPS group. Baseline characteristics of patients are summarized in Table 1.

3.2. Procedural outcomes and radiation exposure from fluoroscopy

Complete PVI was achieved in both groups. Additional left atrial linear ablations were performed at a slightly higher rate in the 2-FPS group (44.7% vs. 33.3%, *P*=.18; Table 2). The 2-FPS group had significantly lower procedural time (229.0 min [IR: 185.0–278.0 min] vs. 275.0 min [IR: 245.0–313.0 min]; *P*<.01), lower fluoroscopy time (15.1 min [IR: 10.7–20.1 min] vs. 24.4 min [IR: 17.5–34.9 min]; *P*<.01), lower DAP (392.0 cGy cm^2 [IR: 289.7–591.4 cGy cm^2] vs. 599.9 cGy cm^2 [IR: 371.4–1337.5 cGy cm^2]; *P*<.01), and lower ED (0.7 mSv [IR: 0.6–1.1 mSv] vs. 1.1 mSv [IR: 0.7–2.5 mSv]; *P*<.01; Table 2). The detailed comparisons of the procedure time, fluoroscopic time, and radiation exposure according to the procedure combinations (PVI only, PVI + cavotricuspid isthmus [CTI] ablation, and PVI + left atrial linear ablation) are described in Table 3. The 2-FPS group showed a trend toward lower procedure time, lower fluoroscopic time, lower DAP, and lower ED regardless of procedure combinations compared with the 4-FPS group (Table 3).

In univariable linear regression model, 2-FPS setting (regression coefficient [B]=−493.4, 95% confidence interval [CI]: −775.9 to −210.9, *P*<.01) and fluoroscopic time (B=35.8, 95% CI=27.1–44.4, *P*<.01) were significantly associated with DAP (Table 4). Due to the multicollinearity between the values of fluoroscopic time and frame setting, multivariable regression analysis was not performed.

3.3. Trends of fluoroscopic time and DAP over time

When we analyzed the trends of fluoroscopic time and DAP over time in patients who underwent PVI or PVI plus CTI ablation only (n=80), the fluoroscopic time and DAP had significantly decreased over time (Fig. 1). The second half of the 2-FPS group showed significantly lower fluoroscopic time (13.1 [IR: 10.9. 16.7] min vs. 19.9 [IR: 12.7, 31.5] min, *P* for trend <.01) and DAP (259.6 [IR: 204.7, 757.0] cGy cm^2 vs. 514.0 [IR: 161.8,

Table 3

Radiation exposure according to the procedure combinations in 2 frames per second and 4 frames per second setting.

	4-FPS, n=57	2-FPS, n=76	*P*
4 PVI only	13 (22.8)	16 (21.1)	
Procedural time, min	260 (235.0, 302.5)	182.5 (138.3, 220.3)	<.01
Fluoroscopy time, min	18.3 (11.9, 20.3)	13.7 (10.2, 17.9)	.17
DAP, cGy cm^2	476.5 (225.2, 944.5)	391.5 (317.9, 644.0)	.64
ED estimate, mSv	0.9 (0.4, 1.8)	0.8 (0.6, 1.1)	.53
4 PVI+CTI ablation	25 (43.9)	26 (34.2)	
Procedural time, min	260.0 (240.0, 289.0)	213.0 (177.5, 267.0)	<.01
Fluoroscopy time, min	25.4 (17.5, 33.1)	13.4 (10.1, 18.6)	<.01
DAP, cGy cm^2	479.7 (271.2, 1174.7)	324.0 (230.2, 529.6)	.08
ED estimate, mSv	1.0 (0.6, 3.2)	0.6 (0.5, 1.1)	.04
4 PVI+liner ablation	19 (33.3)	34 (44.7)	
Procedural time, min	305.0 (273.0, 392.0)	257.5 (210.0, 304.8)	<.01
Fluoroscopy time, min	29.7 (21.1, 43.1)	15.8 (12.5, 22.8)	<.01
DAP, cGy cm^2	907.6 (513.6, 1498.0)	435.0 (313.5, 594.3)	<.01
ED estimate, mSv	2.0 (1.1, 2.7)	0.8 (0.6, 1.1)	<.01

Values are expressed as n (%), means ± standard deviation, or medians (interquartile range).
CTI = cavotricuspid isthmus, DAP = dose area product, ED = effective dose, FPS = frames per second, PVI = pulmonary vein isolation.

1701.5] cGy cm^2, *P* for trend <.01) compared with the first half of the 4-FPS group (Fig. 1).

3.4. CT-related radiation exposure

In both study groups, most patients underwent CT before catheter ablation (>98%, Table 5). DLP was higher in the 4-FPS group compared to that in the 2-FPS group; however, the difference was not statistically significant (1432.3 ± 335.0 cGy cm vs. 1286.2 ± 593.0 cGy cm, *P* = .08). Similarly, ED was higher in the 4-FPS group, but this difference was also not statistically significant (20.1 ± 4.7 mSv vs. 18.0 ± 8.3 mSv, *P* = .08; Table 5).

3.5. Complications

No instances of cardiac tamponade occurred in either group. One patient in the 2-FPS group experienced a cerebellar stroke 1 day after the procedure, and achieved a full neurological recovery. This patient had received uninterrupted dabigatran administration for preprocedural anticoagulation. Another patient in the 2-FPS group had a minor tongue laceration from electrical cardioversion during the ablation procedure. We concluded that neither of these adverse events was related to the use of 2-FPS.

Table 4

Linear regression analysis for prediction of dose area product.

	B	95% CI	*P*
2-FPS	−493.4	−775.9 to −210.9	<.01
BMI, kg/m^2	28.8	−20.8 to 78.4	.25
Fluoroscopic time, min	35.8	27.1–44.4	<.01

B = regression coefficient, BMI = body mass index, CI = confidence interval, FPS = frame per second.

3.6. Recurrence of AT

Over a mean follow-up duration of 331 ± 197 days, AT recurred in 20 patients (35.1%) in the 4-FPS group and 27 patients (35.5%) in the 2-FPS group (*P* = .96). Kaplan–Meier survival analysis revealed no significant between-group difference in this respect (log rank, *P* = .25; Fig. 2).

4. Discussion

To the best of our knowledge, our study is the first to examine the feasibility of extremely low-frame-rate fluoroscopy (2-FPS) during AF catheter ablation. In this study, the efficacy and safety of AF procedure using a 2-FPS setting was comparable to that of the 4-FPS setting. Considering the higher radiation exposure (7369–8690 cGy cm^2) reported in conventional 7.5-FPS settings,[7,19] we believe that utilizing either 2-FPS or 4-FPS modes may substantially decrease radiation exposure without significantly compromising the therapeutic efficacy. Currently, the 2-FPS setting is routinely used at our institution for ablation procedures for AF, as well as in other contexts such as supraventricular tachycardia, atrial flutter, and ventricular tachycardia.

Interestingly, our present 2-FPS patient cohort had lower procedure and fluoroscopic durations than in our 4-FPS group, even though the typical RF application setting (power, duration) has remained unchanged during the use of 2-FPS. This finding should be interpreted with caution because there was an 8-month gap between the treatments of patients in the 4-FPS and 2-FPS groups. Indeed, the operators had made considerable efforts to reduce radiation exposure during that period by reducing the fluoroscopy dependency (Fig. 1) and adjusting the collimator. We

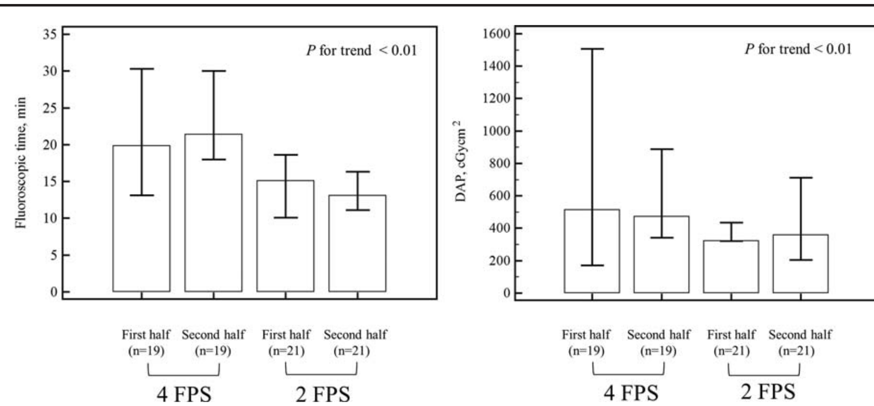

Figure 1. Trends of fluoroscopic time and DAP over time in patients who underwent PVI or PVI plus CTI ablation only. Columns indicate median value and bars indicate 25th and 75th values. CTI = cavotricuspid isthmus, DAP = dose area product, FPS = frames per second, PVI = pulmonary vein (electrical) isolation.

Table 5

Radiation exposure from computed tomography in the study population.

	4-FPS (n=57)	2-FPS (n=76)	P
Computed tomography, n (%)	56 (98.2)	75 (98.7)	.99
DLP, cGy cm	1432.3±335.0	1286.2±593.0	.08
ED estimate, mSv	20.1±4.7	18.0±8.3	.08

Values are expressed as n (%) or means±standard deviation.
DLP=dose length product, ED=effective dose, FPS=frames per second.

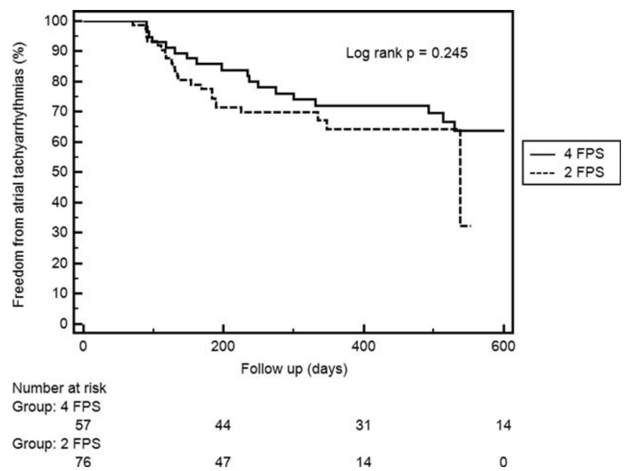

Figure 2. Kaplan–Meier survival curves for recurrence of atrial tachyarrhythmia according to fluoroscopy frame rate. FPS=frames per second.

postulate that it may also reflect the learning curve for low-frame-rate fluoroscopy and the ablation procedure itself. Indeed, the total procedure time was also decreased regardless of the procedure combinations.

Theoretically, a 38% reduction in fluoroscopic time (4-FPS: 24.4 min → 2-FPS: 15.1 min) along with a change from 4-FPS to 2-FPS should result in approximately 70% reduction in DAP. However, only a 30% reduction was observed (4-FPS: 599.9 cGy cm^2 → 2-FPS: 392.0 cGy cm^2). However, this finding should be interpreted carefully. During the AF ablation procedure, we often acquired cineangiography for visualization of PVs and left atrium, and we also used higher frame rate (usually 7.5-FPS) fluoroscopy to assess the cardiac contour to check the presence of cardiac tamponade whenever the patients became hemodynamically unstable. In addition, BMI, a major determinant of radiation dose,[20] was higher in the 2-FPS group. These confounders might offset the radiation-reducing benefits of 2-FPS versus 4-FPS in the multivariable model. Nevertheless, this result might better reflect our actual AF ablation practice. We may not benefit much from 2-FPS setting, compared with 4-FPS setting in clinical practice for the aforementioned reasons. Using fluorography rather than cineangiography might be another useful way to overcome this limitation and further reduce the radiation as previously suggested.[21]

Significant efforts have been made to decrease radiation hazards for patients and operators during AF ablation. Avoidance of left anterior oblique view, proper adjustment of the tube and table position, and active use of collimation can minimize the radiation dose.[20] Schneider and colleagues demonstrated the efficacy of 4-FPS fluoroscopy for AF ablation,[7] and reported a mean DAP of 837±647 cGy cm^2, which was consistent with the DAP of 4-FPS fluoroscopy in our present study (599.9 cGy cm^2 [IR: 371.4–1337.5 cGy cm^2]). A new image-integration technique (CartoUnivu) for merging fluoroscopic images with an electroanatomical map in a single plane has been developed. This technology has been reported to decrease the radiation exposure compared with conventional 3D mapping, and appears to have a relatively short learning curve (5–6 cases).[22,23] Unfortunately, the use of this system is limited by its high cost in Korea. The DAP reported with CartoUnivu (476.5±282.0 cGy cm^2) was comparable to that in the 2-FPS group in the present study (392 cGy cm^2 [IR: 289.7–591.4 cGy cm^2]).[23] However, this new technology does not significantly decrease radiation during catheter placement and trans-septal catheterization. Therefore, a widely applicable and simple strategy to decrease the radiation dose throughout the procedure (i.e., from the diagnostic to the ablation phase) is urgently needed. In addition to PVI, a left atrial linear lesion procedure was safely and effectively performed in both the 2-FPS and 4-FPS groups in the present patient series. No patient underwent left atrial linear ablation with the CartoUnivu system in previous reports.[19,22] Therefore, we conclude that a simple reduction in the fluoroscopy rate should be immediately achievable in most clinical settings.

Trans-septal puncture may be the most concerned step under low-frame-rate fluoroscopic guidance in AF ablation procedure. This procedure could be challenging especially in patients with anatomical atrial septal abnormality such as atrial septal defect closure, chest wall deformity, or dextrocardia. However, these patients were not included in the present study. Trans-septal sheath assembly was advanced into the left atrium after confirmation of left atrial access by pressure monitoring in every case and contrast injection in selected cases. Fortunately, we did not experience any difficulty with this method in the present study even with low-frame-rate fluoroscopic settings (2–4 FPS). Aksu et al[24] suggested a deep inspiration maneuver as a reliable and safe method for trans-septal puncture after failed, conventional attempts. We believe that this method could be a good option to overcome challenging cases of trans-septal puncture.

CT images acquired before catheter ablation can provide detailed anatomical information about the left atrium and PVs, as well as the anatomical relationship between the PVs and esophagus. These data are a valuable resource for planning the procedure and avoiding life-threatening complications such as left atrium–esophageal fistula.[25] However, in the present study, ED from the preprocedural CT scan was 12-fold greater than that from the ablation procedure. An ultra-low-dose CT protocol for the left atrium and PVs has been recently introduced (reported ED 0.41±2.7 mSv), which is much lower dose than that in the present study.[26] Other nonradiation emitting approaches should also be considered for young women, who are at increased risk of radiation-induced complications.[27] Given the large dose of radiation exposure, low-dose CT examinations, preprocedural cardiac magnetic resonance imaging, and/or intraprocedural intracardiac echocardiograms should also be considered as alternatives. Our institute recently began to implement a new CT protocol with adjusted scan range, gating settings, and X-ray pulses to decrease radiation exposure. As a consequence of these efforts, we decreased CT ED to 80% of that associated with the previous setting. The mean ED with this new CT protocol was 3.4±1.1 mSv as assessed in a series of 27 consecutive patients treated in October 2015.

During the 331±197 days of follow-up, approximately 65% of patients were free from recurrent AT in present study. Because the study population consisted of patients with paroxysmal and persistent AF, the recurrence rate could not be directly compared to those from previous studies. Also, the patients in previous well-designed randomized control trials on AF ablation had undergone extensive monitoring for detection of recurrent AT (7 days Holter monitoring at 3, 6, 12, 18, and 24 months[28] or regular 24 h Holter monitoring plus trans-telephonic monitor during the 18 months of follow up[29]). Considering this, we may have underestimated the recurrence rate of AT compared to these studies. In these studies, the recurrence rate of AT was reported to be 15% during the 2 years of follow-up in patients with paroxysmal AF[28] and 41% to 54% during the 18 months of follow-up in patients with persistent AF.[29]

The retrospective study design, single-center settings, and a relatively small sample sizes are notable first limitations of our study. Even though the baseline characteristics were not statistically different between 4-FPS and 2-FPS groups, there is a chance of being underpowered. Even though we enrolled consecutive eligible patients and employed a homogenous procedure pattern by 2 operators, the possibility of a potential selection bias cannot be ruled out. Second, we only enrolled patients who were undergoing AF ablation, and our findings may not apply to other procedures such as coronary angiography that require higher-quality cine images. Third, owing to the retrospective nature of the analysis, the radiation exposure parameters could not be compared with those of conventional 7.5-FPS fluoroscopy because these data were not routinely recorded when 7.5-FPS fluoroscopy was used. Fourth, we did not separately record the DAP and fluoroscopy time for each step of the procedure (i.e., diagnostic catheter placement, trans-septal puncture, PVI, and additional substrate modification). Thus, we could not assess the rate-limiting step for radiation exposure or identify the step for which low-dose fluoroscopy would be maximally beneficial.

In conclusion, the 2-FPS and 4-FPS fluoroscopy protocols are both feasible and safe for catheter ablation of AF. In addition, its use is associated with a substantial reduction in radiation exposure when compared with results from previous related studies. Although no evidence exists to date suggest that the current levels of fluoroscopy present significant danger to patients, we should strive to further decrease radiation exposure. In this regard, our present findings are valuable in that they illustrate how a simple approach can markedly decrease radiation exposure in AF ablation.

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References

[1] Estner HL, Deisenhofer I, Luik A, et al. Electrical isolation of pulmonary veins in patients with atrial fibrillation: reduction of fluoroscopy exposure and procedure duration by the use of a non-fluoroscopic navigation system (NavX). Europace 2006;8:583–7.

[2] Khaykin Y, Oosthuizen R, Zarnett L, et al. CARTO-guided vs. NavX-guided pulmonary vein antrum isolation and pulmonary vein antrum isolation performed without 3-D mapping: effect of the 3-D mapping system on procedure duration and fluoroscopy time. J Interv Card Electrophysiol 2011;30:233–40.

[3] Dixit S, Marchlinski FE, Lin D, et al. Randomized ablation strategies for the treatment of persistent atrial fibrillation: RASTA study. Circ Arrhythm Electrophysiol 2012;5:287–94.

[4] Han S, Hwang C. How to achieve complete and permanent pulmonary vein isolation without complications. Korean Circ J 2014;44:291–300.

[5] Rostock T, Salukhe TV, Steven D, et al. Long-term single- and multiple-procedure outcome and predictors of success after catheter ablation for persistent atrial fibrillation. Heart Rhythm 2011;8:1391–7.

[6] Weerasooriya R, Khairy P, Litalien J, et al. Catheter ablation for atrial fibrillation: are results maintained at 5 years of follow-up? J Am Coll Cardiol 2011;57:160–6.

[7] Schneider R, Lauschke J, Schneider C, et al. Reduction of radiation exposure during ablation of atrial fibrillation. Herz 2015;40:883–91.

[8] Moon J, Lee HJ, Kim JY, et al. Prognostic implications of right and left atrial enlargement after radiofrequency catheter ablation in patients with nonvalvular atrial fibrillation. Korean Circ J 2015;45:301–9.

[9] Rogers DP, England F, Lozhkin K, et al. Improving safety in the electrophysiology laboratory using a simple radiation dose reduction strategy: a study of 1007 radiofrequency ablation procedures. Heart 2011;97:366–70.

[10] Lee S-Y, Kim J, Lee S-H, et al. Reduction of radiation exposure during catheter ablation for paroxysmal supraventricular tachycardia: the effect of a low frame rate of digital pulsed fluoroscopy. Int J Cardiol 2014;177:573–4.

[11] Calkins H, Kuck KH, Cappato R, et al. 2012 HRS/EHRA/ECAS Expert consensus statement on catheter and surgical ablation of atrial fibrillation: recommendations for patient selection, procedural techniques, patient management and follow-up, definitions, endpoints, and research trial design: a report of the Heart Rhythm Society (HRS) Task Force on Catheter and Surgical Ablation of Atrial Fibrillation. Developed in partnership with the European Heart Rhythm Association (EHRA), a registered branch of the European Society of Cardiology (ESC) and the European Cardiac Arrhythmia Society (ECAS); and in collaboration with the American College of Cardiology (ACC), American Heart Association (AHA), the Asia Pacific Heart Rhythm Society (APHRS), and the Society of Thoracic Surgeons (STS). Endorsed by the governing bodies of the American College of Cardiology Foundation, the American Heart Association, the European Cardiac Arrhythmia Society, the European Heart Rhythm Association, the Society of Thoracic Surgeons, the Asia Pacific Heart Rhythm Society, and the Heart Rhythm Society. Heart Rhythm 2012;9:632–96.

[12] Jung BC, Kim NH, Nam GB, et al. The Korean Heart Rhythm Society's 2014 statement on antithrombotic therapy for patients with nonvalvular atrial fibrillation: Korean Heart Rhythm Society. Korean Circ J 2015;45:9–19.

[13] Jais P, Hocini M, Hsu LF, et al. Technique and results of linear ablation at the mitral isthmus. Circulation 2004;110:2996–3002.

[14] Hocini M, Jais P, Sanders P, et al. Techniques, evaluation, and consequences of linear block at the left atrial roof in paroxysmal atrial fibrillation: a prospective randomized study. Circulation 2005;112:3688–96.

[15] Kim JB, Yang DH, Kang JW, et al. Left atrial function following surgical ablation of atrial fibrillation: prospective evaluation using dual-source cardiac computed tomography. Yonsei Med J 2015;56:608–16.

[16] Schultz FW, Zoetelief J. Dose conversion coefficients for interventional procedures. Radiat Prot Dosimetry 2005;117:225–30.

[17] Ector J, Dragusin O, Adriaenssens B, et al. Obesity is a major determinant of radiation dose in patients undergoing pulmonary vein isolation for atrial fibrillation. J Am Coll Cardiol 2007;50:234–42.

[18] Hausleiter J, Meyer T, Hermann F, et al. Estimated radiation dose associated with cardiac CT angiography. JAMA 2009;301:500–7.

[19] Christoph M, Wunderlich C, Moebius S, et al. Fluoroscopy integrated 3D mapping significantly reduces radiation exposure during ablation for a wide spectrum of cardiac arrhythmias. Europace 2015;17:928–37.

[20] Lakkireddy D, Nadzam G, Verma A, et al. Impact of a comprehensive safety program on radiation exposure during catheter ablation of atrial fibrillation: a prospective study. J Interv Card Electrophysiol 2009;24:105–12.

[21] Hwang J, Lee SY, Chon MK, et al. Radiation exposure in coronary angiography: a comparison of cineangiography and fluorography. Korean Circ J 2015;45:451–6.

[22] Cano O, Alonso P, Osca J, et al. Initial experience with a new image integration module designed for reducing radiation exposure during electrophysiological ablation procedures. J Cardiovasc Electrophysiol 2015;26:662–70.

[23] Akbulak RO, Schaffer B, Jularic M, et al. Reduction of radiation exposure in atrial fibrillation ablation using a new image integration module: a prospective randomized trial in patients undergoing pulmonary vein isolation. J Cardiovasc Electrophysiol 2015;26:747–53.

[24] Aksu T, Guler TE, Yalin K, et al. A novel deep inspiration maneuver for difficult transseptal puncture. Am J Cardiol 2017;119:428–33.

[25] Kanaji Y, Miyazaki S, Iwasawa J, et al. Pre-procedural evaluation of the left atrial anatomy in patients referred for catheter ablation of atrial fibrillation. J Cardiol 2015;67:115–21.
[26] Annoni AD, Andreini D, Pontone G, et al. Ultra-low-dose CT for left atrium and pulmonary veins imaging using new model-based iterative reconstruction algorithm. Eur Heart J Cardiovasc Imaging 2015;16: 1366–73.
[27] Budoff MJ, Achenbach S, Blumenthal RS, et al. Assessment of coronary artery disease by cardiac computed tomography: a scientific statement from the American Heart Association Committee on Cardiovascular Imaging and Intervention, Council on Cardiovascular Radiology and Intervention, and Committee on Cardiac Imaging, Council on Clinical Cardiology. Circulation 2006;114:1761–91.
[28] Cosedis Nielsen J, Johannessen A, Raatikainen P, et al. Radiofrequency ablation as initial therapy in paroxysmal atrial fibrillation. N Engl J Med 2012;367:1587–95.
[29] Verma A, Jiang CY, Betts TR, et al. Approaches to catheter ablation for persistent atrial fibrillation. N Engl J Med 2015;372:1812–22.