Clinical Investigation

Adjusted Left Atrial Emptying Fraction

as a Predictor of Procedural Outcome after Catheter Ablation for Atrial Fibrillation

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Structural remodeling of the left atrium is a risk factor for recurrent arrhythmia after catheter ablation for atrial fibrillation; however, data are sparse regarding the role of functional left atrial remodeling in predicting procedural outcomes. We evaluated whether left atrial transport function could be used to predict recurrent atrial fibrillation. From July 2008 through August 2010, we enrolled 202 consecutive patients who underwent catheter ablation for atrial fibrillation (paroxysmal=120, persistent=82). Left atrial volumes (LAVs) were measured by means of multislice computed tomography at every 10% of the R-R interval, and measurements were adjusted for body surface area to yield the LAV index (LAVI) at baseline. The left atrial emptying fraction (LAEF) was calculated according to LAV differences. During the mean follow-up period of 10 ± 4 months after a single ablation procedure, atrial fibrillation recurred in 59 patients (paroxysmal=19, persistent=40). Multivariate analysis revealed that persistent atrial fibrillation, early mitral inflow velocity, $LAVI_{max}$, $LAVI_{min}$, LAEF, $LAVI_{max}$/LAEF, and $LAVI_{min}$/LAEF were all independent predictors of atrial fibrillation, but the best predictor was $LAVI_{min}$/LAEF (β=1.329, P=0.001). The cutoff value was 1.61 (mL/m^2)/%, and the sensitivity and specificity were 74.6% and 62.2%, respectively (area under the curve=0.761). Our study shows that adjusted left atrial emptying fraction with use of multislice computed tomography might be a useful, noninvasive method to select patients for ablation. ***(Tex Heart Inst J 2015;42(3):216-25)***

Key words: *Atrial fibrillation/physiopathology; atrial function, left/physiology; cardiac volume; catheter ablation; heart atria/pathology/ultrasonography; predictive value of tests; preoperative care/methods; recurrence; ROC curve; tomography, X-ray computed/methods*

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Atrial fibrillation (AF) is the most prevalent sustained atrial arrhythmia, and its prevalence increases with human age. Atrial fibrillation accounts for approximately one third of hospitalizations for cardiac rhythm disturbances. It is also the chief thromboembolic cause of stroke, and it is associated with a 2-fold increase in mortality rates and a marked reduction in functional ability and quality of life.[1] Despite the use of potent antiarrhythmic medications, AF recurrence after cardioversion remains frequent, leading to the need for catheter ablation (CA) procedures. Since an exponential increase in CA for AF was documented, left atrial volume (LAV) and LAV index (LAVI) have proved to be powerful predictors of procedural outcomes and indicators of structural remodeling.[2,3]

Investigators have suggested that functional recovery of the left atrium (LA) might be more important than structural reverse remodeling of the LA after CA for AF because long-term anticoagulation is necessary in patients with contractile dysfunction of the LA, despite a maintained sinus rhythm.[4] Furthermore, investigators have shown that evaluating LA pump function combined with LAV enables a more accurate diagnosis of paroxysmal AF (PAF) than do conventional values.[5,6] However, data are sparse concerning the role of functional LA remodeling in predicting procedural outcomes.

Identifying the arrhythmic substrates and evaluating the structural and functional changes in the atria by means of noninvasive methods can be useful in selecting patients for rhythm-control therapy, including CA, early in the disease process.[7] Multislice computed tomography (MSCT) is an accurate method for evaluating LAV, with low interobserver variability. In this study, we used MSCT to quantify LA pump function and structural changes before CA. The aim of this work was to determine whether evaluating LA pump function with the use of MSCT is useful for predicting AF recurrence after CA. This approach would aid in selecting the most appropriate ablation approach for individual AF-ablation candidates. In addition, this approach would help to predict AF recurrence before the initiation of rhythm-control therapies in patients.

Patients and Methods

We identified and prospectively included 218 subjects who had undergone successful CA for AF at our center from July 2008 through August 2010. After a review of the medical records, 16 patients were excluded in accordance with the exclusion criteria. The remaining 202 patients (mean age, 54.1 ± 8.4 yr; 21.8% women) were consecutively enrolled in the study population. Of these, 120 had PAF and 82 had persistent AF (PeAF).

The exclusion criteria were as follows: age >80 years, cardiomyopathy, valvular or coronary artery disease, congestive heart failure, left ventricular (LV) dysfunction, hepatic or renal disease, an acute cardiovascular or cerebrovascular event in the previous 3 months, major trauma or surgery in the previous 3 months, hyperthyroidism, uncontrolled hypertension, malignancy, connective tissue disease, and acute or chronic inflammatory diseases. All antiarrhythmic drugs except for amiodarone were discontinued at least 5 half-lives before the procedure. Amiodarone was discontinued at least 8 weeks before. All patients were receiving continuous anticoagulation therapy with a target international normalized ratio of 2 to 3. The patients were allowed to continue taking other drugs without changes until the end of the study period. Each participant signed an informed consent form before enrolling in the study, which was approved by the Korea University Hospital Human Research Committee and was performed in accordance with institutional guidelines.

Echocardiography

Two-dimensional transthoracic echocardiography (TTE) and MSCT were performed in all participants before the procedure, with use of a Vivid 7® cardiac ultrasound system (GE Vingmed Ultrasound AS; Horten, Norway). The LAVs were measured at every 10% of the R-R interval with use of MSCT and were adjusted for body surface area, which was described as the LAVI. The LA emptying fraction (LAEF) was calculated on the basis of the changes in the LAVs. A single, experienced investigator who had no knowledge of the MSCT results measured and interpreted all recorded echocardiograms with use of an Echopac™ 6.3.4 computerized, offline analysis station (GE Vingmed).

Left Atrial Volumes and Left Atrial Pump Function on MSCT

The MSCT images were acquired with use of a Brilliance CT 64-channel scanner (Koninklijke Philips N.V.; Best, The Netherlands). Imaging was performed in the craniocaudal direction and in the helical mode with retrospective electrocardiographic (ECG) gating, during a patient's single inspiratory breath-hold. Eighty mL of intravenous iodinated Ultravist® contrast medium (370 mg/mL) (Schering AG; Berlin, Germany) was administered, followed by 40 mL of a mixture of normal saline solution and contrast medium (7:3 ratio), both at a rate of 5 mL/s. For adequate gating and to minimize motion artifacts, subjects with heart rates faster than 80 beats/min were given β-blockers. The following values were used during imaging: 64 × 0.625-mm detector collimation; tube voltage, 80 kVp; gantry rotation time, 420 ms; tube current, 1,000 mAs; and pitch, 0.2. Axial multiphase images were reconstructed (slice thickness, 0.8 mm; increment, 0.5 mm) with use of retrospective ECG gating. The estimated effective radiation dose received by the patient was 3.31 ± 1.06 mSv. Images were restricted on every 10th phase of the cardiac cycle. Image analysis was performed on an Extended Brilliance Workspace version 3.5.4.1056 workstation (Philips). A 10-frame cine loop that covered the entire cardiac cycle was obtained to determine LA pump function. The endocardial border of the LA was semiautomatically traced for each axial image slice. On each image, the LA appendage and pulmonary veins (PVs) were carefully excluded at their junctions with the LA. The voxels in each slice were added to determine the 3-dimensional (3D) LAV (Fig. 1). The LAVs were plotted as a function of time to generate time-volume curves. The maximal LAV (LAV_{max}) and minimal LAV (LAV_{min}) were determined from the time-volume curves. In the simplified method, referred to as the fixed-phase analysis, the LAV at 40% of the R-R interval was used as the LAV_{max}, and the LAV at 100% of the R-R interval was used as the LAV_{min}. The LAEF was calculated with use of the following formula: $LAEF = 100 \times (LAV_{max} - LAV_{min})/LAV_{max}$.

During AF, only LAV_{max}, LAV_{min}, and LAEF were evaluated. To determine the intra- and interobserver reproducibility of the MSCT, 2 experienced investigators repeated the LAV_{max}, LAV_{min}, and LAEF measurements at 2 different time points for 20 randomly selected subjects. We measured all values in sinus rhythm with use of MSCT.

Ablation Procedures

After double-transseptal puncture was performed, systemic anticoagulation was achieved by means of heparin administered intravenously, to maintain an activated clotting time between 300 and 350 s. After the 3D geometry of the LA and PVs was determined with use of an EnSite™ NavX™ 3D electroanatomic mapping system (St. Jude Medical, Inc.; St. Paul, Minn), all PVs were mapped with use of a Lasso® decapolar circular catheter (Biosense Webster, a Johnson & Johnson company; Diamond Bar, Calif). Open irrigation, which was performed with use of a 3.5-mm THERMOCOOL® tip-deflectable catheter (Biosense Webster), enabled mapping and ablation. Radiofrequency energy was delivered at a maximum power output of 25 to 30 W, a flow rate of 17 to 30 mL/min, and a maximum

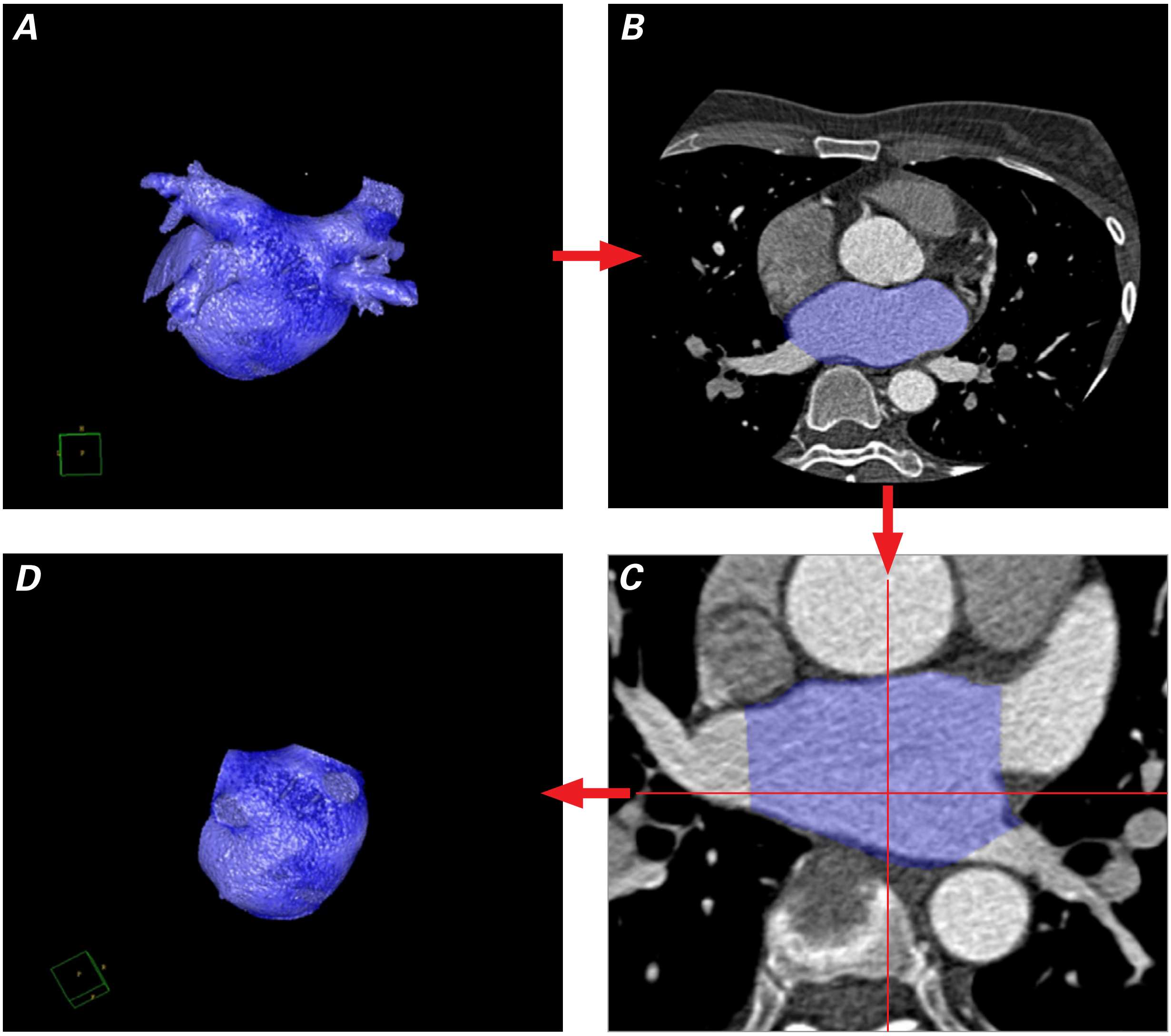

Fig. 1 *Multislice computed tomograms were used to measure left atrial volume.* ***A****) Typical output of the automatic segmentation of the left atrium.* ***B****) The axial and* ***C****) coronal views show the manually excluded pulmonary veins and left atrial appendage (the red lines are automatic guiding lines to check the computed tomography).* ***D****) Semiautomatically processed 3-dimensional image shows the left atrial body.*

temperature of 48 °C. A stepwise ablation procedure was performed in every patient, regardless of AF type. Initially, all patients underwent wide circumferential PV isolation (CPVI). For patients who remained in AF after CPVI or had induced AF that was sustained for longer than 5 min, complex fractionated atrial electrogram (CFAE) ablation on both atria was performed until the AF was terminated. We defined CFAE as electrograms with a fractionated interval between 50 and 120 ms. In patients with PeAF or induced typical atrial flutter (AFL) or both, a cavotricuspid isthmus line was generated, and the bidirectional block was confirmed by means of a differential pacing maneuver. The 2 procedural endpoints were no early recurrence of AF after direct-current cardioversion under isoproterenol infusion (5 µg/min); and noninducibility of sustained, organized AFL.

Follow-Up Protocol

If no complications arose during the procedure, the patients began warfarin anticoagulation therapy without antiarrhythmic medications. All enrolled subjects were prospectively monitored for recurrent AF for up to 6 months after the 3-month blanking period (which should be applied after ablation when reporting efficiency outcomes of a single procedure), through monthly outpatient clinical visits. The patients also underwent 48-hour Holter monitoring at 1, 3, and 6 months after CA. An ECG was performed during each visit and whenever a patient reported palpitations. In addition, patients were interviewed by a nurse practitioner by telephone at 2-week intervals and were instructed to call whenever they experienced symptoms. If any instance of AF or AFL was documented during the 6-month follow-up period, the patient was considered to have a clinical recurrence of arrhythmia, and antiarrhythmic medications were prescribed.

Statistical Analysis

Student *t* tests or analyses of variance (ANOVA) were performed to compare continuous variables between populations (presented as mean ± SD with 95% confidence intervals [CIs]). The rank-sum method and the Kolmogorov-Smirnov Z test were performed to validate the unpaired *t* tests and ANOVAs for nonparametric factors, respectively. Two-tailed Fisher exact tests or χ^2 tests were used to compare categorical variables. Bland-Altman analyses were performed to express the reproducibility of LAV measurements between each investigator. All statistical analyses were performed with use of SPSS software, version 13.0 (IBM Corporation; Armonk, NY). Statistical significance was defined as a 2-sided P value of <0.05.

How well LAVs differentiated patients with and without a given outcome (recurrent AF) was evaluated by the area under a receiver operating characteristic (ROC) curve, which ranged from 0 to 1, where 0.5 corresponded to no discrimination (random performance) and 1 indicated perfect discrimination. A stepwise multivariable regression analysis was performed to determine which independent variables were significantly associated with AF recurrence. Clinical variables, including LAV, sex, age, LV dysfunction, AF duration, type of AF, type of ablation procedure, and total number of cardiovascular comorbidities, were evaluated by means of univariate analysis to determine significant associations with the dependent variable. Variables selected by univariate analysis were then incorporated into a multivariable regression analysis and were fitted by a forward stepwise selection procedure (probability values for entry and removal, 0.05 and 0.1, respectively). If possible, continuous variables were used unless otherwise specified, such as for LV dysfunction, to prevent loss of information during regression analysis. No one who performed measurements knew anything about the patients, especially the outcomes of their ablation procedures.

Results

In all patients, CA was performed without immediate complications. For the overall cohort, 59 patients (29.2%) developed recurrent AF (PAF=19, PeAF=40) during the mean follow-up period of 10 ± 4 months after a single ablation procedure. Table I shows the baseline clinical characteristics of the patients, stratified by AF-recurrence status at the time of follow-up. Patients who developed recurrent AF were older, were more likely to have non-PAF, and were more likely to have had an unknown arrhythmia duration before CA.

Echocardiographic Values Associated with Recurrence

Table II shows a comparison of the echocardiographic values of patients with recurrent AF and those who remained in sinus rhythm after CA. According to the univariate analysis, variables significantly associated with AF recurrence were higher anteroposterior LA diameter (AP–LAD) (44.6 ± 7.5 vs 40.5 ± 6.4 mm, P <0.001) on the M-mode tracing, and early mitral inflow velocity (E velocity) (82.7 ± 18.1 vs 70.8 ± 19 cm/s, P=0.006). In addition, patients with recurrent AF had a lower LV ejection fraction (LVEF) relative to those without recurrence (0.60 ± 0.1 vs 0.63 ± 0.09, P=0.055), which is consistent with the results of a previous study.[8]

Adjusted Left Atrial Emptying Fraction and Atrial Fibrillation by MSCT

In patients without recurrent AF, the $LAVI_{max}$ and $LAVI_{min}$ were significantly lower than those with recurrence (67 ± 20.1 vs 81.2 ± 25.6 mL/m^2 and 44.8 ± 19.3 vs 64.3 ± 26.5 mL/m^2, respectively; P <0.001) (Table III). According to the univariate analysis, $LAVI_{max}$, $LAVI_{min}$, LAEF, LAVI indexed to LA pump function ($LAVI_{max}$/LAEF and $LAVI_{min}$/LAEF), and simple LAV were independent predictors of AF recurrence after CA. In the multivariate model, age, sex, history of previous AF, AF duration, PeAF, E velocity, $LAVI_{max}$, $LAVI_{min}$, LAEF, $LAVI_{max}$/LAEF, and $LAVI_{min}$/LAEF were also independent predictors of recurrent AF after CA. Of these variables, $LAVI_{min}$/LAEF was the most important predictor (β=1.329, P=0.001). Figure 2 shows the ROC curves for the $LAVI_{max}$, $LAVI_{min}$/LAEF, LAEF, and $LAVI_{max}$/LAEF as predictors of recurrent AF after CA. The area under the curve (AUC) was 0.664 for $LAVI_{max}$, vs 0.754 for LAEF and 0.752 for $LAVI_{max}$/LAEF (P <0.001). The best discriminating value of $LAVI_{min}$/LAEF to predict recurrent AF was 1.61 (mL/m^2)/%, which had a sensitivity of 74.6% and a specificity of 62.2% (AUC=0.761). The Bland-Altman plot shows the LAV-measurement reproducibility between each investigator (Fig. 3).

In univariate analysis, non-PAF, B-type natriuretic peptide level, LVEF, AP–LAD, E velocity, LAV_{max}, LAV_{min}, LAEF, $LAVI_{max}$, $LAVI_{min}$, $LAVI_{max}$/LAEF, and $LAVI_{min}$/LAEF were significantly associated with AF recurrence after CA. In multivariate analysis, $LAVI_{min}$/LAEF (odds ratio, 1.675 [range, 1.058–2.651]; P=0.028) was the best independent predictor of AF recurrence after CA at the 12-month follow-up evaluation (Table IV).

TABLE I. Characteristics of the 202 Patients at Baseline

Variable	No Recurrent AF (n=143)	Recurrent AF (n=59)	*P* Value
Male	115 (80.4)	43 (72.9)	0.263
Age (yr)	56.6 ± 11.8	57.5 ± 10.6	0.646
Height (cm)	168 ± 8.4	168.4 ± 8	0.737
Body mass index (kg/m²)	24.8 ± 2.7	25.1 ± 2.9	0.432
Nonparoxysmal atrial fibrillation	42 (29.4)	40 (67.8)	<0.001
Hypertension	62 (43.3)	26 (44.1)	1
Diabetes mellitus	20 (14)	12 (20.3)	0.291
Systolic blood pressure (mmHg)	139.7 ± 12.2	129 ± 15.7	0.498
Diastolic blood pressure (mmHg)	79.4 ± 11.6	80.7 ± 9.9	0.477
Congestive heart failure	17 (11.9)	10 (16.9)	0.366
Stroke	13 (9)	5 (8.5)	1
Peripheral vascular disease	0	1 (1.7)	0.292
Angina pectoris	14 (9.8)	7 (11.9)	0.623
Lung disease	7 (4.9)	1 (1.7)	0.442
Medications			
ACE inhibitor	12 (8.4)	6 (10.2)	0.787
Angiotensin receptor blocker	46 (32.1)	19 (32.2)	1
Calcium channel blocker	27 (18.9)	16 (27.1)	0.256
β-Blocker	34 (23.8)	11 (18.6)	0.463
Digoxin	2 (1.4)	2 (3.4)	0.582
Diuretic	40 (28)	22 (37.3)	0.24
Antiarrhythmic	117 (81.9)	51 (86.4)	0.536
Aspirin	13 (9)	1 (1.7)	0.071
Clopidogrel	115 (80.4)	48 (81.3)	1
Warfarin	113 (79)	56 (94.9)	0.006
Statin	37 (25.9)	10 (16.9)	0.202
Trimetazidine	8 (5.6)	8 (13.6)	0.082
Laboratory Profile			
Total cholesterol (mg/dL)	175 ± 35.6	174.9 ± 33.4	0.989
Triglycerides (mg/dL)	117 ± 26.7	122 ± 53.3	0.522
HDL cholesterol (mg/dL)	46.6 ± 11.3	46.8 ± 11.5	0.929
LDL cholesterol (mg/dL)	110.5 ± 31.4	112 ± 29.6	0.747
C-reactive protein (mg/dL)	2.796 ± 7.435	1.739 ± 2.577	0.361
BNP (pg/mL)	381.6 ± 756.3	717.5 ± 1,077	0.042
White blood cell count (×10³/μL)	7.181 ± 4.451	6.833 ± 1.974	0.565
Platelets (×10³/μL)	220.8 ± 48.7	220 ± 57	0.914
Platelet volume (fL)	8.263 ± 1.352	9.822 ± 9.929	0.243

ACE = angiotensin-converting enzyme; AF = atrial fibrillation; BNP = B-type natriuretic peptide; HDL = high-density-lipoprotein; LDL = low-density-lipoprotein

Values are presented as mean ± SD or as number and percentage. $P < 0.05$ was considered statistically significant.

Discussion

In this study, we have shown that adjusted LA emptying fraction ($LAVI_{min}$/LAEF) can be used to predict procedural outcome after CA for AF. To our knowledge, this is the first study to report this finding. Despite emerging evidence that LAVI is a better predictor of a first episode of AF than are LAV and AP–LAD, few studies evaluating the determinants of AF recurrence after CA have focused on LA pump function, and no studies have examined the role of adjusted LA emptying fraction as a predictor of recurrent AF after CA. Previous investigators showed that atrial volume determined by means of TTE was superior to the atrial diameter index for predicting in patients after CA. In particular, multivariate analysis showed LAVI to be an independent predictor.[2] However, the results have not been consistent, and such variation in results might be explained by the different study designs and inaccuracies associated with TTE-based measurements.

TABLE II. Echocardiographic Characteristics Influencing Recurrent Atrial Fibrillation after Catheter Ablation

Variable	No Recurrent AF (n=143)	Recurrent AF (n =59)	*P* Value
LVIDd (mm)	49.6 ± 4.7	50.1 ± 5.7	0.477
LVIDs (mm)	31.6 ± 5.4	32.6 ± 6.7	0.29
LVEF	0.63 ± 0.09	0.60 ± 0.1	0.055
AP–LAD (mm)	40.5 ± 6.4	44.6 ± 7.5	<0.001
E (cm/s)	70.8 ± 19.9	82.7 ± 18.1	0.006
Deceleration time (ms)	217.6 ± 77	220.4 ± 148.2	0.896
E′ (cm/s)	7.7 ± 2.5	8.4 ± 2.3	0.333
E/E′ ratio	9.6 ± 3.3	10.8 ± 7.5	0.339

AF = atrial fibrillation; AP–LAD = anteroposterior left atrial diameter; E = peak mitral flow velocity of early rapid filling wave due to atrial contraction; E′ = early diastolic velocity of mitral annulus; LVEF = left ventricular ejection fraction; LVIDd = left ventricular interventricular diameter during diastole; LVIDs = left ventricular interventricular diameter during systole

Values are presented as mean ± SD. $P < 0.05$ was considered statistically significant.

TABLE III. Multislice Computed Tomographic Characteristics Influencing Recurrent Atrial Fibrillation after Catheter Ablation

Variable	No Recurrent AF (n=143)	Recurrent AF (n=59)	*P* Value
LAV_{max} (mL)	120.1 ± 34.9	146.7 ± 43.2	<0.001
LAV_{min} (mL)	80.3 ± 33.5	116.2 ± 45.4	<0.001
LAEF (%)	34.4 ± 12.2	22.6 ± 11.8	<0.001
$LAVI_{max}$ (mL/m^2)	67 ± 20.1	81.2 ± 25.6	<0.001
$LAVI_{min}$ (mL/m^2)	44.8 ± 19.3	64.3 ± 26.5	<0.001
$LAVI_{max}$/LAEF ([mL/m^2]/%)	2.4 ± 1.9	5.8 ± 5.8	<0.001
$LAVI_{min}$/LAEF ([mL/m^2]/%)	1.7 ± 1.5	5 ± 5.7	<0.001
Ablation time (min)	129.8 ± 46.4	122.6 ± 39.3	0.297

AF = atrial fibrillation; LAEF = left atrial emptying fraction; LAV_{max} = maximal left atrial volume; LAV_{min} = minimal left atrial volume; $LAVI_{max}$ = maximal left atrial volume index; $LAVI_{min}$ = minimal left atrial volume index

Values are presented as mean ± SD. $P < 0.05$ was considered statistically significant.

As mentioned above, LA contractile function is difficult to evaluate. In some studies, there were significant differences in the LAV and LAEF values that were measured by means of TTE and MSCT. However, our group previously showed that LAVs and LAEF determined by means of TTE correlated well with those determined by means of 10-phase analysis with MSCT, even when AF was the underlying rhythm.[6] In addition, previous investigators have shown that MSCT has excellent spatial and temporal resolution, and the LAV can be accurately quantified by using the modified Simpson method,[9] which enables the evaluation of LAEF with use of volumetric data and reflects global contractility with excellent reproducibility.[10]

It is unclear whether LA enlargement leads to recurrent AF directly or whether it is a consequence of AF. Left atrial enlargement, which represents atrial anatomic remodeling, might be associated with electrical remodeling. These changes possibly provide an arrhythmogenic substrate that might increase the risk of recurrent AF. The hallmark of LA structural remodeling is myocardial fibrosis, which leads to progressive LA dilation. Thus, time-dependent, adaptive regulation of cardiac myocytes is needed to maintain homeostasis against external stress. The extent and reversibility of atrial remodeling depends on the strength and duration of the stress exposure. The most prevalent atrial myocyte stressors are volume/pressure overload and tachycardia. Increased volume/pressure overload leads to chamber dilation and stretching of the atrial myocardium, which provides a substrate for sustained AF.[11]

A longer duration of AF causes progressive remodeling and increased LA size and volume.[12-14] Accordingly, PeAF is considered to be a more advanced stage of arrhythmia than PAF is. Our patients with non-PAF also had a higher AF-recurrence rate. Furthermore, patients with recurrent AF had a larger LA dimension and a higher E velocity on TTE.

In this study, successful ablation was achieved in 70.8% of our patients during the follow-up period, which is comparable to the results of other studies, whose

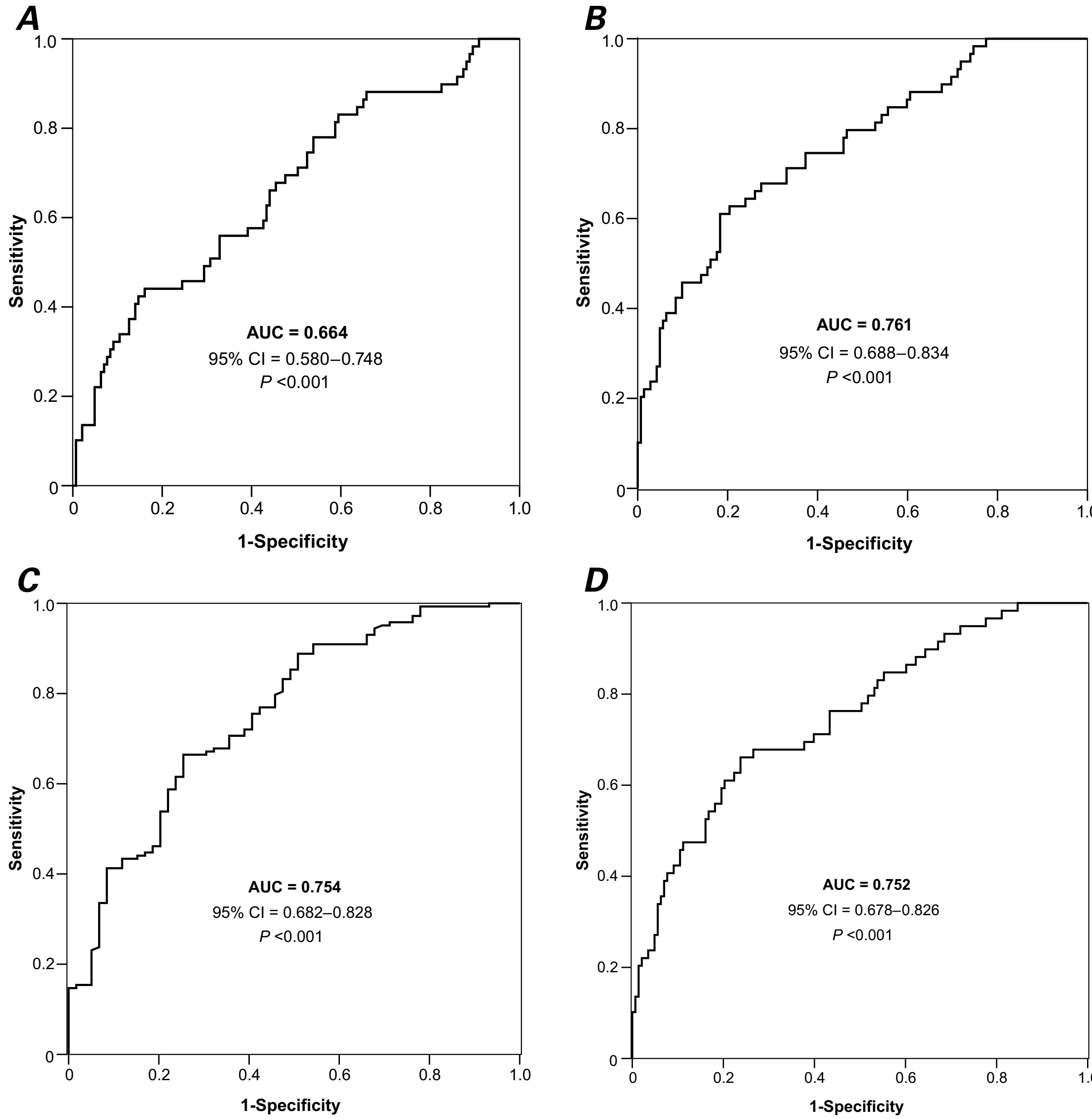

Fig. 2 *Receiver operating characteristic curves show* ***A****) $LAVI_{max}$,* ***B****) $LAVI_{min}$/LAEF,* ***C****) LAEF, and* ***D****) $LAVI_{max}$/LAEF to be predictors of recurrent atrial fibrillation after catheter ablation. The area under the curve (AUC) was 0.664 for $LAVI_{max}$ vs 0.754 for LAEF and 0.752 for $LAVI_{max}$/LAEF (*P *<0.001). The best predictor of recurrent atrial fibrillation was $LAVI_{min}$/LAEF, with a cutoff value of 1.61 (mL/m²)/% (sensitivity, 74.6%; specificity, 62.2% [AUC=0.761]).* P *<0.05 was considered statistically significant.*

CI = confidence interval; LAEF = left atrial emptying fraction; $LAVI_{max}$ = maximal left atrial volume index; $LAVI_{min}$ = minimal left atrial volume index

investigators reported variable recurrence rates between 40% and 86%.[2,15,16] Conversely, this means that 30% to 60% of AF patients might experience recurrence after CA. Therefore, the ability to predict recurrence can help to guide decisions about antiarrhythmic therapy and long-term anticoagulation before such regimens are initiated.[17] In our study, PeAF, E velocity, $LAVI_{max}$, $LAVI_{min}$, LAEF, $LAVI_{max}$/LAEF, and $LAVI_{min}$/LAEF were independent predictors of recurrent AF after CA. Of these, $LAVI_{min}$/LAEF was the most important predictor of arrhythmia recurrence (β=1.329, P=0.001). With a cutoff value of 1.61 (mL/m^2)/%, the sensitivity was 74.6% and the specificity was 62.2% (AUC=0.761), which is consistent with the idea that increased volume/pressure overload is the basis of sustained AF.

Some investigators have reported an association between the M-mode LA diameter and recurrent AF after CA.[18,19] In clinical practice, M-mode echocardiography can be used to determine LA diameter but not to accurately quantify LA size, because of the irregular geometry of the LA and the angulation of the ultrasound beam. Left atrial volume measured by means of 2-dimensional TTE is perhaps more accurate in determining LA size.[2] However, MSCT enables direct measurement of LAV, such that no assumptions about the complex shape of the LA are necessary. In another study, fixed-phase analysis in the context of MSCT yielded excellent spatial resolution and thus simply and reliably determined LA volume and function in patients with

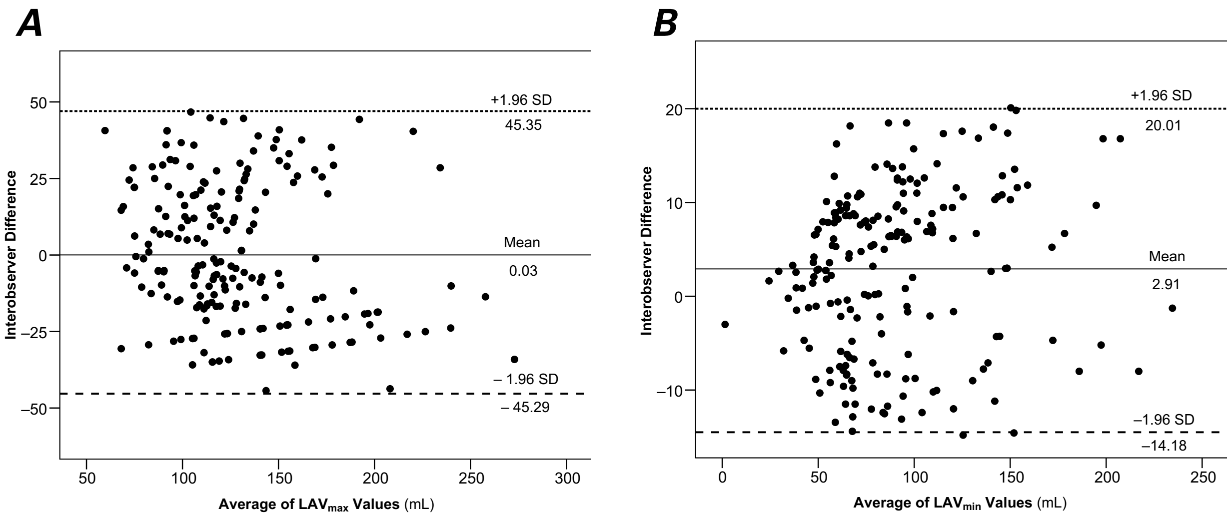

***Fig. 3** Bland-Altman plots show the reproducibility of multislice computed tomographic measurements of **A**) LAV_{max} and **B**) LAV_{min} between 2 investigators.*

LAV_{max} = maximal left atrial volume; LAV_{min} = minimal left atrial volume; SD = standard deviation

TABLE IV. Univariate and Multivariate Logistic Regression Analyses of Recurrent Atrial Fibrillation after Catheter Ablation at 12-Month Follow-Up Evaluation

	Univariate Analysis		Multivariate Analysis	
Variable	**Odds Ratio** (95% CI)	***P* Value**	**Odds Ratio** (95% CI)	***P* Value**
Nonparoxysmal atrial fibrillation	4.896 (2.549–9.403)	<0.001	—	—
BNP	1.000 (1.000–1.001)	0.059	—	—
LVEF	0.967 (0.935–0.999)	0.043	—	—
AP–LAD	1.118 (1.038–1.204)	0.003	—	—
E	1.032 (1.008–1.055)	0.008	—	—
LAV_{max}	1.018 (1.010–1.027)	<0.001	1.023 (1.005–1.041)	0.013
LAV_{min}	1.023 (1.014–1.032)	<0.001	1.027 (1.007–1.047)	0.007
LAEF	0.923 (0.896–0.95)	<0.001	0.957 (0.913–1.004)	0.071
$LAVI_{max}$	1.028 (1.013–1.043)	<0.001	1.038 (1.006–1.071)	0.019
$LAVI_{min}$	1.038 (1.023–1.054)	<0.001	1.048 (1.012–1.086)	0.008
$LAVI_{max}$/LAEF	1.386 (1.202–1.599)	<0.001	1.662 (1.077–2.566)	0.022
$LAVI_{min}$/LAEF	1.501 (1.259–1.79)	<0.001	1.675 (1.058–2.651)	0.028

AP–LAD = anteroposterior left atrial diameter; BNP = B-type natriuretic peptide at baseline; CI = confidence interval; E = peak mitral flow velocity of early rapid filling wave due to atrial contraction; LAEF = left atrial emptying fraction; LAV_{max} = maximal left atrial volume; LAV_{min} = minimal left atrial volume; $LAVI_{max}$ = maximal left atrial volume index; $LAVI_{min}$ = minimal left atrial volume index; LVEF = left ventricular ejection fraction at baseline

Left atrial indices were calculated with the use of multislice computed tomography. P <0.05 was considered statistically significant.

AF.[20] For these reasons, we used MSCT to quantify LA transport function and structural changes before CA, and we found that adjusted LAEF measured by means of MSCT can be used as a reliable predictor of recurrent AF after CA.

Study Limitations

This study has several limitations. First, asymptomatic episodes of AF might not have been detected during the follow-up period. In addition, the symptomatic episodes might not have been AF episodes exclusively. However, all patients in this study had symptomatic AF before CA. Second, MSCT images were acquired during each patient's single inspiratory breath-hold, whereas most echocardiographic images were acquired during patients' normal breathing. This difference might have caused minor variations in the estimated LAVs. Third, the administration of iodinated contrast medium caused radiation exposure and could have led to adverse events. Furthermore, MSCT has a relatively lower temporal resolution than does biplane 2-dimensional echocardiography, which might have yielded poor estimations of the changes in LAV at different phases during the cardiac cycle. To minimize this last limitation, 10- or 20-phase analyses have been conducted to evaluate LAV during the cardiac cycle.[21] Fourth, variable procedures performed in each patient might have affected the recovery of LA size and function. To minimize this limitation, we strove to perform AF ablation in a consistent fashion in all patients.

Last, because the study included a small number of patients, large-scale and long-term follow-up studies are warranted to confirm our findings and to provide definitive cutoff values for predicting recurrent AF after CA.

Conclusion

We found that LAVI indexed to LA emptying fraction ($LAVI_{min}$/LAEF) was the best independent predictor of AF recurrence after CA, and more so than simple LAVI. The evaluation of LAEF might be a useful, noninvasive method of selecting patients before CA. Further studies with larger sample sizes will be necessary to confirm the independent predictive value of arrhythmia recurrence after CA in patients with prior AF.

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