Left Atrial Volume Assessment in Atrial Fibrillation Patients undergoing Ablation, using 2-D Echocardiography and Invasive Three-Dimensional CARTO and its Predictive Value in Recurrence of Atrial Fibrillation after Ablation

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ABSTRACT

Background: The most prevalent cardiac arrhythmia, atrial fibrillation (AF), is expected to affect around 16 million people worldwide by 2050. Because AF is linked to increased mortality, thromboembolic strokes, myocardial infarction, and heart failure, it costs the US health care system over $6 billion yearly.

Aim of the Work: This study aimed to assess left atrial volume (LAV) in atrial fibrillation patients using non-invasive echocardiography and invasive 3D mapping (CARTO) and to assess its predictive value in recurrence of atrial fibrillation after ablation.

Patient and methods: The study was conducted on 42 consecutive patients with non-valvular AF who underwent pulmonary vein isolation and came to follow up in the Outpatient Clinic of the Cardiology Department at El Galaa Military Hospital and Benha University Hospital.

Results: LAV measured by CARTO was significantly higher compared to LAV measured by Echocardiography. Recurrence rate after AF ablation was significantly higher in patients with LAVI more than 36 ml/m^2 (47.8%) than patients with LAVI less than 36 ml/m^2 (5.3%). LAV by CARTO could significantly predict the AF recurrence with cutoff value > 98 ml. High BMI related significantly with the recurrence of AF after AF ablation. Recurrence was significantly lower in patients with ablation catheter type Thermo Cool Smart Touch than patients with EZ steer.

Conclusion: Optimizing the benefits of AF catheter ablation required determining each patient's risk of recurrence as it assists in identifying individuals who stand to gain the most from AF ablation as well as the technique and approach employed for ablation.

Keywords: Left atrial volume, Atrial fibrillation, 2-D Echocardiography, Invasive three-dimensional CARTO.

INTRODUCTION

One of the most common arrhythmias, atrial fibrillation (AF) is linked to a lower quality of life as well as a higher risk of heart failure, ischemic stroke, and all-cause death. In terms of enhancing quality of life, radiofrequency catheter ablation (RFCA) has demonstrated its effectiveness in patients with atrial fibrillation [(1)].

Radiofrequency catheter ablation decreased hard clinical outcomes such as ischemic stroke and worsening of heart failure, and all cause death in a subgroup of patients [(2)]. But, radiofrequency catheter ablation is not a cure for atrial fibrillation (AF), particularly in cases when the AF is chronic. After radiofrequency catheter ablation, a considerable number of AF patients have atrial tachycardia (AT) or recurrence of AF. Despite recent improvements in catheter ablation techniques, one-third of AF patients still have recurrence of AF following ablation, which frequently necessitates repeat of ablation surgeries. In order to maximize the benefits of catheter ablation and choose the right patients, it is necessary to evaluate each patient's risk of recurrence. This process helps to identify the individuals who stand to gain the most from AF ablation. The kind and amount of AF in the left atrium (LA) are two risk factors linked to recurrence following radiofrequency catheter ablation [(3)].

Echocardiography is the most popular and effective non-invasive imaging method currently available for determining LA size. LA volume can be ascertained during the radiofrequency catheter ablation process using electro-anatomic (CARTO) mapping, enabling three-dimensional reconstruction of the LA [(4)].

A three-month blanking interval is theoretically justified by the current understanding that early recurrence is associated with temporary local inflammation and tissue necrosis as a result of catheter ablation. Recent research, however, casts doubt on this, showing that patients who experienced an early recurrence had a markedly higher risk of a late recurrence [(5, 6)].

Mujovic *et al.* [(7)] found that, at three months following the initial radiofrequency catheter ablation, individuals with early recurrence had a considerably greater incidence of pulmonary vein reconnection (88.2% vs. 41.7%) than patients without early recurrence. Patients exhibiting low success rates typically require enlarging of the ablation lesions in accordance with further modifications to the left atrial (LA) substrate.

The aim of this study was to assess left atrial volume in atrial fibrillation patients using non-invasive echocardiography and invasive 3D mapping (CARTO) and to assess its predictive value in recurrence of atrial fibrillation after ablation.

PATIENTS AND METHODS

This prospective and retrospective cohort study included 42 consecutive patients with non-valvular AF who underwent pulmonary vein isolation and came for

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follow up in the Outpatient Clinic in the Cardiology Department at El Galaa Military Hospital and Benha University Hospital. Recruitment started in January 2022 and ended in July 2023. All study population underwent Trans-Thoracic Echocardiography, before AF ablation procedure.

Inclusion Criteria: Patients with non-valvular paroxysmal or persistent AF. The diagnosis of atrial fibrillation (AF) was made using electrocardiographic data, which included Holter monitoring. The AF categorization process followed the most recent recommendations for atrial fibrillation treatment from the European Society of Cardiology, whereby the two patterns; persistent AF and paroxysmal AF were distinguished [8].

When AF ends on its own or with the use of anti-arrhythmic medications (AADs) within seven days of the commencement, it is referred to as paroxysmal AF. The definition of persistent AF is ongoing AF that lasts longer than seven days [9].

Exclusion Criteria: Patients with acute myocardial infarction, cardiogenic shock, indications for aortocoronary bypass surgery, valvular AF, structural heart disease, chronic AF patients, acute stroke, and uncontrolled hypertension with a systolic blood pressure more than 160 mmHg [9].

Method: All study population underwent history taking, clinical examination to assess AF type and medical history, height and weight to calculate BMI and BSA using Mosteller equation [10]. ECG or Holter (electrocardiographic evidence) for documentation and classification of AF [8]. Echocardiographic and Doppler studies: A Vivid E9 Ultrasound AS, Horten, Norway matrix array probe with a 1.7/3.4 MHz transducer frequency range was used for transthoracic echocardiography (TTE), which was carried out in a supine or left lateral decubitus posture (Figure1). Standard parasternal and apical views were obtained for the two-dimensional pictures. The biplane Simpson's method was used to calculate ejection fractions (EF). Every Doppler recording was acquired at a 100 mm/s sweep speed [8].

Figure (1): Vivid E9 Ultrasound AS, Horten, Norway

In apical 4-chamber and apical 2-chamber views at ventricular end systole (maximum LA size), left atrial (LA) volumes were measured using the Simpson method: 20 discs derived from perpendicular perspectives [11] (Figure 2).

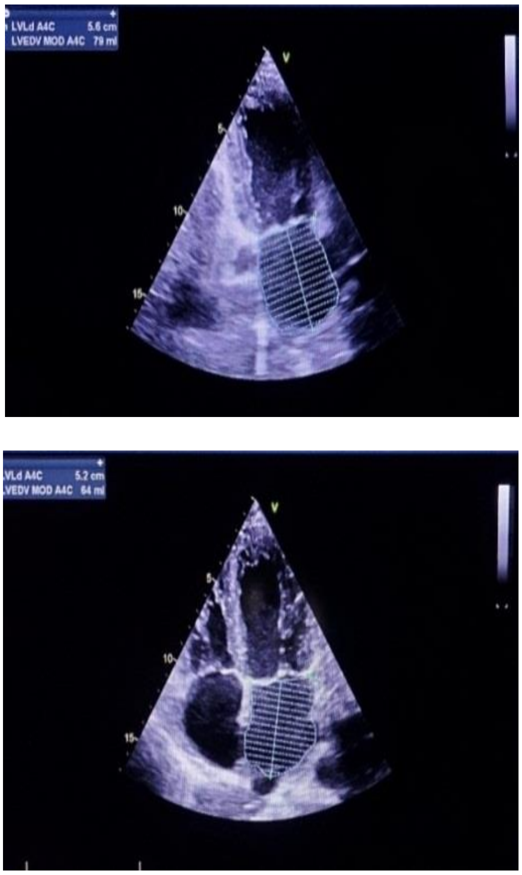

Figure (2): LA volume (2D mode) in (a) Apical 4 chamber and (b) apical 2 chamber view using disc method

LAVI, which is expressed in milliliters per square meter (ml/m^2), was calculated by indexing the LA volume to the body surface area (BSA). After determining weight and height, the Mosteller method was used to compute BSA [8].

AF ablation procedure:

To minimize pain for the patient and prevent the acquired electroanatomical maps from being dislocated, all procedures were performed under general anesthesia of the **CARTO 3 (Biosense Webster, CA, USA) version 4,** and after trans-esophageal echocardiography (TEE) to exclude LAA thrombus. Decapolar catheter was introduced through the right femoral vein to the coronary sinus. Two trans-septal punctures were performed under fluoroscopy and with the aid of TEE to increase safety and decrease the rate of any expected complications **(Figure 3)**.

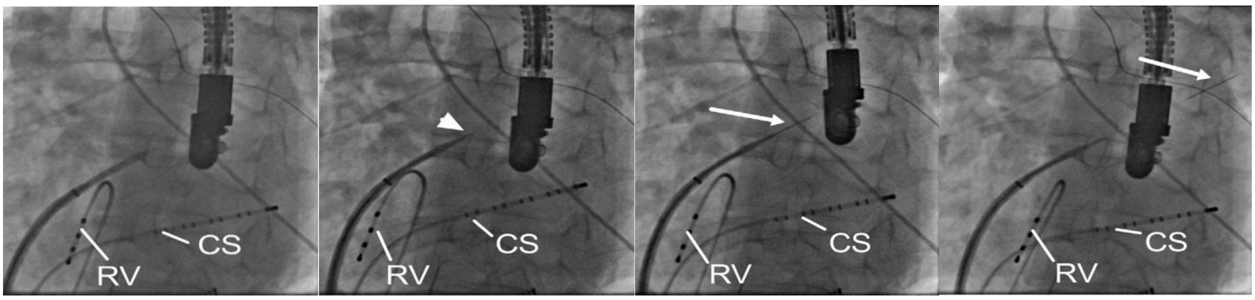

Figure (3): Transseptal puncture. (a) Fluoroscopic view (left anterior oblique LAO 40) with the tip of the transseptal sheath in the fossa ovalis. (b) The Brockenbrough needle was advanced and the tip of the needle (arrowhead) produced a marked tenting toward the left atrial lateral wall without passing through the septum. (c) Transseptal puncture wire was advanced through the needle and entered the left atrium. The piercing wire's tip spontaneously curved back after passing through the sepsis, creating an atraumatic distal tip. A radiopaque marker (arrow) was visible on the piercing wire, situated directly distal to the atraumatic tip. The upper branch of the left inferior pulmonary vein was the pulmonary vein into which the puncture wire (arrow) was cautiously introduced [(12)]**.**

Two long sheaths (**PREFACE® Sheaths, Biosense Webster**) were passed into the left atrium: One for the saline-irrigated ablation catheter [(EZ STEERTM Bi-Directional THERMOCOOL® Catheter Biosense Webster) or (THERMOCOOL SMARTTOUCHTM contact force Catheter Biosense Webster)] and the other for the circular mapping catheter [(LASSOTM NAV, Biosense Webster) or (PENTARAY® NAV, Biosense Webster)] catheters ACT continued to be higher than 300 [(13)] **(Figure 4).**

Figure (4): (a) PREFACE® Sheaths, Biosense Webster, (b) LASSO™ NAV, Biosense Webster, (c) PENTARAY® NAV, Biosense Webster, (d) EZ STEER™ Bi-Directional THERMOCOOL® Catheter Biosense Webster and (e) THERMOCOOL SMARTTOUCH™ contact force Catheter Biosense Webster.

The map did not include any mapping spots for pulmonary vein ostia. Precise demarcation of the mitral annulus and pulmonary vein ostia was seen. The LA appendage's opening and proximal portion were always mapped. 3D digital map software interpolations over the coordinates of several endocardial tags were used to create the LA anatomically. **LAV (left atrial volume) CARTO** was computed utilizing a Biosense software built-in calculation tool, excluding the volume of the lung appendage and pulmonary veins [(14)]**.** Subsequent to the ipsilateral left and right PVs, a wide area circumferential ablation (WACA) was performed using point-by-point ablation of the circumferential PV antrum. The 40 °C temperature limit, 25–35 W of RF energy, and 13–20 mL/min infusion rate were all used during ablation. The catheter tip was moved down the line every 20 seconds. In order to prevent thermal harm to the oesophagus, the power was lowered to 20–25 W at the LA posterior wall. The eradication of PV musculature conduction in all pulmonary veins, as determined by either PVP dissociation or absence, was referred to as complete PV isolation. Pulmonary vein potential (PVP) on the mapping catheter, while pacing from a coronary sinus or LA catheter is known as entrance block. Confirmation of PVI was obtained by showing either entrance block or exit block (Which occurs when pacing from the catheter in the PV does not result in atrial activity [(26)]) **(Figures 5 & 6).**

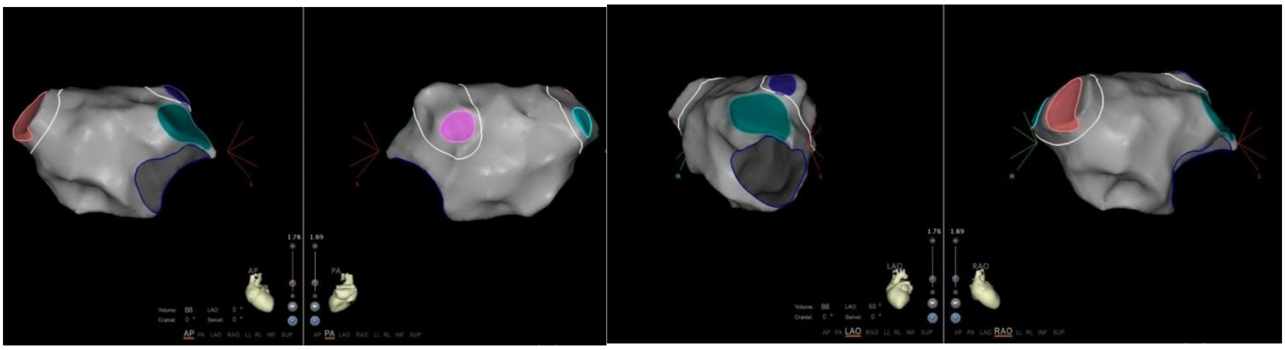

Figure (5): (a), (b) AP, PA, LAO and RAO views of the left atrium with 3D virtual map anatomical construction using CARTO 3 (Biosense Webster, CA, USA) version 4 with LA volume of 88 ml excluding both sides of pulmonary veins and LAA volumes (notice the delineated mitral annulus).

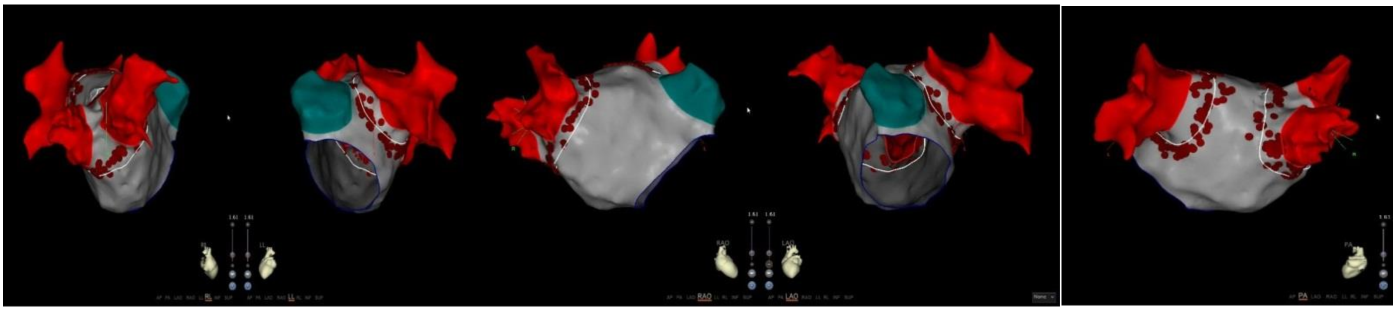

Figure (6): (a, b and c) RL, LL, RAO, LAO, PA views of the left atrium with 3D virtual map anatomical construction using CARTO 3 (Biosense Webster, CA, USA) version 4. The left atrial appendage (LAA) is the green structure, and the right and left upper and lower pulmonary veins are the red structures. Observe the point-by-point ablation of the circumferential PV antrum (continuous red dots) surrounding the ipsilateral left and right veins in the lungs [Wide area circumfrential ablation (WACA)].

Further substrate alteration was also allowed if the operator thought it was more critical than trigger point eradication. If prolonged arrhythmia was created during pulmonary vein isolation, further ablation such as low-voltage zone ablation and linear ablation, or complicated fractionated atrial electrogram-guided ablation, was carried out at the operator's discretion [(15)].

5- Follow up of patients peri-operative and for 6 months after ablation procedure:

Prior to ablation, baseline patient data were documented including test findings prior to the surgery, medical history, concomitant conditions, and stroke risk scores**.** Patients were closely observed for any problems associated to the surgery, such as bleeding, thromboembolic events, and/or pericardial effusion or tamponade. In order to identify any palpitation symptoms and potential recurrence of AF, the patient was followed up with at 1, 3, and 6 months following the treatment. ECG and 24- and 48-hour ECG Holter monitoring were used for additional examination. The data gathered were as follows: A thorough physical examination was performed prior to ablation, a surface electrocardiogram was taken one, three, and six months following the treatment, Holter monitoring was limited to patients who had palpitations, and unrecorded or unexplained symptoms were all part of the history gathering process. When a case was symptomatic, they were always asked to record their ECG [(16)].

After the first three months following ablation, a clinical recurrence was defined as any episode of symptomatic or asymptomatic atrial tachyarrhythmia that lasted more than thirty seconds and was captured on an ECG or Holter monitoring.

Some important definitions [(17)]:

AF and AT were both components of atrial tachyarrhythmia. An early recurrence (the blanking period) was defined as any atrial tachyarrhythmia that persisted for longer than 30 seconds following RFCA. and any late recurrence lasting more than 90 days after RFCA was classified as a late recurrence. When an entire 10-second surface electrocardiogram strip revealed AT or AF, it was additionally categorized as an early or late recurrence, depending on the situation.

Management of antiarrhythmic and anticoagulation medications and stroke prevention:

Early AF recurrences may be avoided by continuing antiarrhythmic drug treatment for a further six weeks to three months [(18)].

Recommendations for stroke risk management peri-catheter ablation:

Systemic anticoagulation with warfarin or a NOAC is maintained for a minimum of two months following ablation. Whether systemic anticoagulation is continued for longer than that depends more on the patient's CHA2DS2-VASc stroke risk factors than on the rhythm status and the procedure's apparent success or failure (Class of recommendation I level of evidence a, according to ESC AF guidelines 2020) [(18)].

According to ESC AF recommendations 2020, pre-procedural stroke risk treatment in AF patients who meet the criteria for stroke risk and who do not take an oral anticoagulant (OAC) before ablation should involve starting anticoagulation and (Class of recommendation I level of evidence c). **[18].**

Therapeutic OAC for a minimum of three weeks before to ablation is preferred. Alternatively, TOE can be used to rule out LA thrombus prior to ablation (Class of recommendation IIa degree of evidence c, per ESC AF recommendations 2020) **[18].**

It is advised that AF catheter ablation procedures be carried out without stopping OAC therapy in patients who have received treatment with edoxaban, rivaroxaban, dabigatran, apixaban, or warfarin (ESC AF guidelines 2020, class of recommendation I degree of evidence a) **[18].**

Ethical approval: Written informed consents were obtained from all patients. The study was conducted according to Helsinki declaration. The study was approved by Cardiology Department at El Galaa Military Hospital and Benha University Hospital.

Statistical analysis

SPSS V 28 (IBM Inc., Armonk, NY, USA) was used for the statistical analysis. The mean and standard deviation (SD) for quantitative variables were displayed. The frequency and percentage (%) for the qualitative characteristics were displayed. The following factors were assessed in order to determine the diagnostic performance: sensitivity to diagnoses: It calculates the proportion of patients' groups that receive real positive results, or diagnostic specificity. Positive predictive value (PPV), which quantifies the frequency of true negative outcomes in a population of people who are not ill, is the proportion of true positive outcomes among all positive outcomes. Negative predictive value (NPV) is the proportion of actual negative outcomes to all bad outcomes. Recipient ROC-curve (operating characteristic curve) analysis: A perfect test is regarded as a curve that goes from the lower left corner to the higher left corner and back to the upper right corner to estimate the relationship between a dependent variable and one (univariate) or more independent variables (multivariate), logistic regression was also used to evaluate the overall test performance (AUC), where an area under the curve (AUC) > 50% indicates acceptable performance and an area about 100% is the best performance for the test). P value ≤ 0.05 is considered to be significant.

RESULTS

Regarding the baseline characteristics of the studied patients, there were 25 (59.52%) males and 17 (40.48%) females, their age ranged from 26 to 63 years with a mean of 46.1 ± 11.19 years. The weight of the studied patients ranged from 64 to 123 Kg with a mean of 91.1 ± 13.59 Kg, the height ranged from 1.58 to 1.93 m with a mean of 1.7 ± 0.08 m and the BMI ranged from 21.48 to 41.58 Kg/m^2 with a mean of 31.05 ± 4.33 Kg/m^2. The BSA that was calculated ranged from 1.7 to 2.45 ml/m^2 with a mean of 2.1 ± 0.18 ml/m^2 [Table 1].

Table (1): Baseline characteristics of the studied patients

		Total (n=42)
Age (years)	**Mean± SD**	46.1 ± 11.19
	Range	26 - 63
Sex	**Male**	25 (59.52%)
	Female	17 (40.48%)
Weight (Kg)	**Mean± SD**	91.1 ± 13.59
	Range	64 - 123
Height (m)	**Mean± SD**	1.7 ± 0.08
	Range	1.58 - 1.93
BMI (Kg/m^2)	**Mean± SD**	31.05 ± 4.33
	Range	21.48 - 41.58
BSA (ml/m^2)	**Mean± SD**	2.1 ± 0.18
	Range	1.7 - 2.45

BMI: body mass index, BSA: body surface area.

LAV measured by CARTO was significantly higher compared to LAV measured by Echocardiography (P<0.001) [Table 2].

Table (2): Comparison between LAV by Echocardiography and LAV by CARTO of the studied patients

		LAV by Echocardi-ography	LAV by CARTO	P - value
LAV (ml)	**Mean± SD**	79.7 ± 14.34	103.6 ± 18.18	**<0.001***
	Range	50 - 107	62 - 138	

LAV: left atrial volume, *: statistically significant as P value <0.05.

At 3 months follow-up, 16 (38.09%) patients had ECG AF or AT and palpitation, (early recurrence), 26 (61.90%) patients had no episodes of AF or palpitation and ECG NSR. At 6 months follow-up, 12 (28.6%) patients had recurrence, 30 (71.4%) patients had no episodes of AF or palpitation and ECG NSR **[Table 3].** The 12 patients who were diagnosed late recurrence group, had early recurrence with a percentage of 75% of early recurrence patients (16 patients).

Table (3): Follow-up of the studied patients

		Total (n=42)
At 3 months	**ECG AF, AT and palpitation (Early recurrence)**	16 (38.09%)
	No episodes of AF or palpitation, ECG NSR	26 (61.90%)
At 6 months	**Recurrence**	12 (28.6%)
	No episodes of AF or palpitation, ECG NSR	30 (71.4%)

ECG: electrocardiogram, AF: atrial fibrillation, NSR normal sinus rhythm.

The AF type was paroxysmal AF in 31 (73.81%) patients and was persistent AF in 11 (26.19%) patients. Of 31 **Paroxysmal AF** cases, 7 (22.58%) had recurrence with a success rate of 77.41%. Of 11 **Persistent AF** cases, 5 (45.45%) had recurrence with a success rate of 54.54% [Table 4].

Table (4): Recurrence of AF according to type

Total (n=42)			
Paroxysmal AF (n=31)	Recurrence	7 (22.58% of Paroxysmal AF cases)	31 (73.81 %)
	Non-Recurrence	24 (77.41% of Paroxysmal AF cases)	
Persistent AF (n=11)	Recurrence	5 (45.45% of Persistent AF cases)	11 (26.19 %)
	Non-Recurrence	6 (54.54% of persistent AF cases)	

This table showed that recurrence was significantly higher in patients with LAVI more than 36 ml/m^2 (47.8%) than in patients with LAVI less than 36 ml/m^2 (5.3%) [Table 5].

Table (5): Comparison between patients with LAVI more than 36 ml/m^2 and patients with LAVI less than 36ml/m2 regarding occurrence of recurrence at 6 months

	LAVI more than 36ml/m 2 N=23	LAVI less than 36ml/m 2 N=19	P value
Recurrence at 6 months	11 (47.8%)	1 (5.3%)	**0.002**

LAV: left atrial volume, *: statistically significant as P value <0.05.

Table (6) showed that recurrence was significantly lower in patients with ablation catheter type Thermo Cool Smart Touch (contact force catheter) (11.1%) than in patients with EZ steer (non-contact force catheter) (41.7%) [Table 6].

Table (6): Comparison between patients with ablation catheter type Thermo Cool Smart Touch and patients with EZ steer (non-contact force catheter) regarding occurrence of recurrence at 6 months

	Ablation catheter type Thermo Cool Smart Touch N=18	EZ steer (non-contact force catheter) N=24	P-value
Recurrence at 6 months	2 (11.1%)	10 (41.7%)	**0.03**

LAV: left atrial volume, *: statistically significant as P value <0.05.

At 6-months follow-up, LAV by CARTO can significantly predict the AF recurrence with AUC of 0.90 and P value of < 0.001, at cutoff value of > 98 ml with 87.4% sensitivity, 73.6 % specificity, 38.1% PPV and 95.6 % NPV [Table 7].

Table (7): Diagnostic accuracy of LAV by CARTO for prediction of AF recurrence at 6-months follow-up

	Cut -off	Sensitivity	Specificity	PPV	NPV	AUC	P value
LAV by CARTO	>98	87.4	73.6	38.1	95.6	0.90	**<0.001***

AF: atrial fibrillation, LAV: left atrial volume, PPV: positive predictive value, NPV: negative predictive value, AUC: area under the curve, *: statistically significant as P value <0.05.

Table (8) showed that recurrence was significantly higher in patients with LAVI more than 36 ml/m^2 (47.8%) than in patients with LAVI less than 36 ml/m^2 (5.3%).

Table (8): Comparison between patients with LAVI more than 36 ml/m^2 and patients with LAVI less than 36 ml/m^2 regarding occurrence of recurrence at 6 months

	LAVI more than 36ml/m2 N=23	LAVI less than 36ml/m2 N=19	P-value
Recurrence at 6 months	11 (47.8%)	1 (5.3%)	**0.002**

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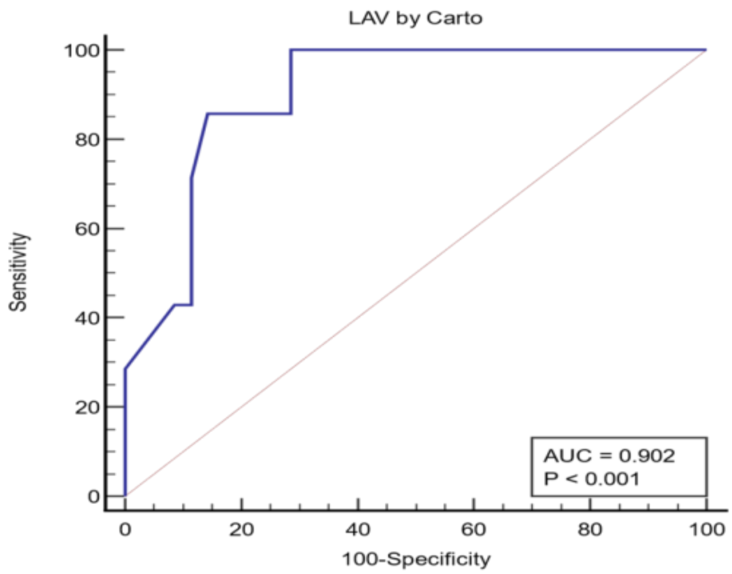

LAV: left atrial volume, *: statistically significant as P value <0.05.

Fig. 7: ROC curve analysis of LAV by CARTO for prediction of AF recurrence at 6-months follow-up.

We discovered that high BMI, LAVI, and LAV (ml) by CARTO were significant predictors of the occurrence of AF recurrence on univariate and multivariate logistic regression analysis [Table 10].

Table (10): Logistic regression analysis for prediction of occurrence of AF recurrence

	Univariate			Multivariate		
	OR	**95% CI**	**P**	**OR**	**95% CI**	**P**
Age (years)	0.810	1.1719 to 2.940	0.634	0.761	1.0986 to 2.624	0.584
Sex	0.791	0.1911 to 3.2753	0.747	0.708	0.1400 to 3.5853	0.677
BMI (Kg/m^2)	1.832	0.9124 to 1.1209	**0.035**	1.140	0.8834 to 1.1927	**0.028**
BSA (ml/m^2)	1.551	0.0983 to 24.467	0.755	4.444	0.1036 to 190.57	0.437
HTN	0.758	0.1889 to 3.0415	0.696	0.511	0.0616 to 4.2356	0.534
DM	0.833	0.1973 to 3.5205	0.804	0.792	0.1054 to 5.9465	0.820
AF type	1.959	0.4418 to 8.6872	0.376	2.217	0.4761 to 10.320	0.310
HR (beats/min)	1.102	0.9938 to 1.2230	0.065	1.096	0.9858 to 1.2182	0.090
SBP (mmHg)	1.031	0.9771 to 1.0881	0.265	1.031	0.9757 to 1.0896	0.278
DBP (mmHg)	1.028	0.9511 to 1.1106	0.488	1.019	0.9361 to 1.1087	0.667
EF (%)	1.135	0.9315 to 1.3827	0.209	1.165	0.9382 to 1.4467	0.167
LAV (ml) by Echo	0.842	0.7341 to 1.1071	0.372	0.955	0.8364 to 1.0852	0.241
LAVI (ml/m^2) by echo	1.259	1.0864 to 1.4583	**0.002**	1.163	0.9902 to 1.3547	**0.003**
LAV (ml) by CARTO	1.214	1.1230 to 1.2846	**<0.001***	1.263	1.0975 to 1.4722	**<0.001***

BMI: body mass index, BSA: body surface area, AF: atrial fibrillation, HR: heart rate, SBP: systolic blood pressure, DBP: diastolic blood pressure, CRP: C-reactive protein, EF: ejection fraction, LAV: left atrial volume, LAVI: left atrial volume index.

DISCUSSION

By 2050, atrial fibrillation (AF), the most common heart arrhythmia, is predicted to impact about 16 million individuals globally. Because AF is linked to increased mortality, thromboembolic strokes, myocardial infarction, and heart failure, it costs the US health care system over $6 billion yearly [19, 20].

Before **Haissaguerre and associates** [21] discovered that radiofrequency catheter ablation (RFCA) was developed and the pulmonary vein was identified as the primary cause of atrial fibrillation (AF), AF was not thought to be a treatable condition**.** Nowadays, a recognized treatment option for AF is pulmonary vein isolation (PVI) via radiofrequency ablation (RFA), which is frequently employed in individuals with symptomatic AF who have not responded to anti-arrhythmic medication therapy. After pulmonary vein separation, the success rate ranges from 50 to 80%, with 60% and 80% for paroxysmal AF and 50% and 60% for chronic AF depending on ablation techniques**, [**The 2020 ESC Guidelines for atrial fibrillation diagnosis and treatment state**].**

AF catheter ablation for PVI should be considered a first-line therapy for rhythm regulation in certain symptomatic individuals. Paroxysmal AF episodes and persistent AF without substantial risk factors for recurrent AF are examples of class IIa degree of evidence B. Evidence class IIb, level C weighing the benefit, risk, and patient's choice before assigning an AAD class I or III patient. Furthermore, after one unsuccessful or intolerant class I or III AAD, the following recommendations for rhythm control are suggested: class I level of evidence A, persistent AF without major risk factors for AF recurrence; and improving symptoms of AF recurrences in patients with paroxysmal AF (proof level B for class I). The goal of AF catheter ablation for PVI is to manage rhythm in patients with paroxysmal and chronic AF who are not able to reduce their symptoms of recurrent arrhythmias with beta-blocker therapy (level B evidence, class IIa). Numerous studies and meta-analyses have clearly shown a considerable increase in quality of life when RFCA is used instead of AADs [2]**.**

Despite recent improvements in catheter ablation techniques, one-third of AF patients still have recurrence of AF following ablation, which frequently necessitates repeat of ablation surgeries. Furthermore, despite recent advancements, the success rate is still subpar, particularly in individuals with non-paroxysmal AF. Depending on the patient's features, the type of AF, the definition of LR, the number of repeat treatments, and the length of follow-up, the reported success rate following initial AF ablation ranges from 40:80%**.** Consequently, determining each patient's risk of recurrence is crucial to maximize the advantages of catheter ablation and choosing the right patients, both of which aid in identifying the individuals who stand to gain the most from AF ablation. Additionally, the method and plan of ablation, particularly for chronic AF, whose recurrence rate is between 40% and 50% [7]**.**

In our opinion, LA volume is a risk assessment tool that, when paired with other AF recurrence prognosticators, may aid in more precise patient selection for RFA. Additionally, an elevated LA volume ought to cause concern and stimulate the search for additional manageable comorbidities that have been demonstrated to independently raise the risk of AF recurrence after RFA [22]**.**

Following an analysis of 21 full-text studies, a few characteristics were listed in 41 review as recurrence predictors. The pre-procedural predictive of the left atrial volume index and left atrial diameter values was found to be significant. The cut-off values for AF LA diameter >50–55 mm and left atrial volume indexed to body surface area > 34 ml/m^2 were identified [23]**.**

The DR-FLASH score is one of the many published, validated scoring systems that predicts a LA substrate favorable for AF recurrence and actual AF recurrence post-RFA. It is based on a number of factors, including age > 65 years, female sex, persistent form of atrial fibrillation, renal dysfunction, diabetes mellitus, and hypertension. According to reports, it can be used to detect patients who have arrhythmogenic substrates. Based on the DR-FLASH score, patients with persistent atrial fibrillation can be categorized into two groups, according to **Sato *et al.*** [23] hypothesis: those who require PVI-plus and those who can get by with PVI alone**.**

In compliance with the 2020 ESC Guidelines for the diagnosis and treatment of atrial fibrillation, we examined 42 patients with non-valvular AF who were candidates for an AF ablation operation. The patients had two types of AF: paroxysmal and persistent. We used the 2D Transthoracic-echocardiography (TTE) and 3D **CARTO 3 (Biosense Webster, CA, USA) version 4,** to evaluate the left atrial volume therefore calculating the left atrial volume index (LAVI). Even though 2D echocardiography has limits when it comes to measure atrial volume, this technique still provides the majority of predictive information [24, 25]**.**

Considered the currently suggested method for LA size estimation, left atrial volume evaluation utilizing the discs formula, obtained from two-dimensional TTE, tends to provide a more accurate assessment of LA size [12]**.**

We found that left atrial volume (LAV) measured by CARTO was significantly higher compared to LAV measured by Echocardiography (P<0.001). This is consistent with **Škňouřil *et al.*** [24] discovery that the LAV acquired by Simpson echocardiographic biplane approach also showed a 20–30% reduction in comparison with the LAV obtained electroanatomically. This study also discovered a strong connection (r=0.9) between the two LAV methods**.**

The presence of an appropriate observer-dependent gain and angulation changes for the echocardiographic window to visualize the endocardial contour, and appropriate measurement timing at the end of ventricular systole can all affect the accuracy of LAV ECHO [26].

Škňouřil *et al.* [24] revealed that anatomically correct projection and picture quality are often competing variables. As a result, biplane assessments may not be absolutely orthogonal and the planes might not be aligned with the chamber's geometric center in order to maximize the cross-sectional area. Consequently, there are two potential explanations for the calculation error: (i) 2D echocardiography's inability to precisely measure the actual volume of complicated atrial shape due to simple geometric assumptions, or (ii) the inability to obtain the necessary photos for biplane evaluation of the endocardial contour and orthogonality [27-33].

It is easy to assume that more spherical structures are only susceptible to underestimating, but non-spherical structures are more likely to be overestimated or underestimated. In addition to the LA's spherical remodeling**,** other factors may also play a role: trapezoidal LA shape**,** enlargement of the funnel shaped Pulmonary veins (PV) antra, LA roof reshaping**,** and dilatation of the LA appendage and anterior LA [29]**. Abecasis *et al.*** showed that the LA volume was linked to AF recurrence following RFA, whereas the LA anterior-posterior diameter (LAD) was not [28]**.** However, other studies have found that lower LAVI readings are connected to an increased chance of recurrence of AF [31]**.** Different sample sizes and patient characteristics may be the cause of the disparate LAVI cut-off values**.**

We studied late recurrence of AF after 3 months, 23 patients had LAVI more than 36 ml/m^2, while 19 patients had LAVI less than 36 ml/m^2. Also, we found that recurrence rate after AF ablation was significantly higher in patients with LAVI more than 36 ml/m^2 (47.8%) than in patients with LAVI less than 36 ml/m^2 (5.3%). This is concordant to **Kranert *et al.*** [8] observations, which revealed that in patients undergoing cardioversion (CV) or catheter ablation, we have found the same LAVI cut-off value**.**

Another finding in our study that LAV by CARTO can significantly predict the AF recurrence with AUC of 0.90 and P value of <0.001, at cutoff value of > 98 ml with 87.4% sensitivity, 73.6 % specificity, 38.1% PPV and 95.6 % NPV. **Piorkowski *et al.*** [4] found that the LA CARTO map and the CT-assessed LAV had a high degree of agreement, and they based their study's LAV measurement on CARTO-derived LAV rather than on CT. **Von Bary *et al.*** [30] demonstrated that pre-ablation LAV as assessed by MDCT or CMRI may be used to forecast the result of a post-PVI procedure. Patients with pre-ablation LAV > 95 ml are more likely to develop persistent AF than patients with LAV ≤ 95 ml in the case of ablation failure and recurrence of AF. While, **Rabbat *et al.*** [31] said that the LAV determined by MR and the LAV obtained via electroanatomic mapping corresponded and agreed well. And so, **Von Bary *et al.*** [30] advised to perform ablation as soon as possible to prevent the ventricle from dilatation in patients with LAV ≤ 95 ml. This is due to the fact that patients with LAV > 95 ml are more likely to have persistent AF in the event that AF recurs, requiring the need for further lesions that also target the substrate, such as ablation in complicated fractionated electrograms or the roof line or mitral isthmus line.

In our study, 31 patients had paroxysmal AF (73.81% of all cases) 7 of them had recurrence (22.58% recurrence of paroxysmal AF cases), success rate was 77.41% of paroxysmal AF cases. The other 11 cases had persistent AF (26.19% of all cases) 5 of them had recurrence (45.45% recurrence of persistent AF cases) and success rate was 54.54% of persistent AF cases. All cases have done pulmonary veins isolation only (PVI).

The use of an anterior mitral line ablation (AML) in addition to standard treatment has been associated with a lower rate of atrial fibrillation (AF/AT) recurrence in patients with persistent atrial fibrillation as compared to individuals who had standard ablation , or posterior line ablation plus PVI. A study conducted by **Sawhney *et al*.** [32] demonstrated that adding linear lesions to the usual PVI procedure is linked to a higher frequency of left atrial flutter in patients with structurally sound hearts and symptomatic PAF than segmental PVI alone. Atrial flutter, which is a recurrence, was caused by an imperfect linear lesion that was drawn during the ablation surgery. The authors recommended against using linear ablation as the first method of ablation for this patient population. Additionally, non-pulmonary vein foci that are situated outside of the circumferential ablation lines may potentially play a role in the onset of AF [34]**.**

When AF or AT recurs, it can be categorized as early (the blanking period) if it happens within three months of RFCA or late (LR) if it happens beyond three months of RFCA [30]**.** Real clinical recurrence is defined as a late recurrence. The blanking period, which lasts for up to 90 days following RFCA, is when early recurrence (ER) is not usually seen as a true clinical recurrence. According to the current definition employed in the majority of research, any AF or AT recurrence in the blanking period, which is an early recurrence, is not regarded as a recurrence [3]**.**

One finding from our study was that 75% of people with early recurrence AF (ERAF) had a late recurrence, and our findings are almost identical with **Nalliah *et al.*** [33]**.** discovered that, throughout the course of a 5-year follow-up, a sizable number (69.6%) of patients who had early recurrence later had late recurrence**,** while **Xue *et al*.** [9] discovered that of the 112 ER patients in his study, 81 (65.90%) had LR**. Nalliah *et al.*** [33] reported that 73% of patients with ERAF had late recurrence AF (LRAF) according to research on the effects of early AF recurrence in the blanking period on long-term results following AF ablation.

After Analysis of the results we found that high Body Mass Index (BMI) related significantly with the recurrence of AF after AF ablation. **Liu *et al.*** [10] found that for every five units rise in BMI, there was a 15% increase in AF recurrence. Along with a significant increase in the risk of AF recurrence at BMIs greater than 35 kg/m^2 and an increasing probability of AF recurrence following ablation with BMI. The findings also showed that obesity or being overweight (BMI > 28 kg/m^2) was positively and independently associated with AF recurrence after ablation. A patient with grade II obesity (BMI > 35 kg/m^2) had a 95% greater risk of developing an AF recurrence. Patients with elevated BMI are more likely to experience an AF recurrence, according to five meta-analyses that have been done. Current guidelines put the weight loss objective at > 10% weight reduction with lifestyle improvements for BMI < 27 kg/m^2 in order to lower the recurrence rate after AF catheter ablation.

We used Ablation catheter type Thermo Cool Smart Touch (contact force catheter) in the AF ablation for 18 patients, while we used EZ steer (non-contact force catheter) in AF ablation of the other 24 cases. We noticed that recurrence was significantly lower in patients with ablation catheter type Thermo Cool Smart Touch (contact force catheter) (11.1%) than patients with EZ steer (non-contact force catheter) (41.7%). **Marijon *et al.*** [35] discovered that during left atrial mapping and pulmonary vein isolation, patients who underwent contact force-guided operation had a considerably lower recurrence rate (10.5%) than those who underwent non-contact force-guided treatment (35.9%).

CONCLUSION

In order to maximize the benefits of AF catheter ablation and to determine which patients are most likely to benefit from it, it is crucial to evaluate each patient's risk of recurrence also the technique and strategy used for ablation. High BMI, LAVI and LAV (ml) by CARTO were significant predictors of occurrence of AF recurrence. Early recurrence had a high significance in prediction of late recurrence. Using of contact force catheters improved results and decreased incidence of AF recurrence after ablation.

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REFERENCES

1. **Mark B, Anstrom J, Sheng S *et al.* (2019):** Effect of catheter ablation vs medical therapy on quality of life among patients with atrial fibrillation: the CABANA randomized clinical trial. Jama, 321 (13): 1275-85.
2. **Marrouche F, Brachmann J, Andresen D *et al.* (2018):** Catheter ablation for atrial fibrillation with heart failure. N Engl J Med., 378: 417–427.
3. **Kim G, Choi I, Boo Y *et al.* (2019):** Clinical and echocardiographic risk factors predict late recurrence after radiofrequency catheter ablation of atrial fibrillation. Sci Rep., 9: 544-552.
4. **Piorkowski C, Hindricks G, Schreiber D *et al.* (2006):** Electroanatomic reconstruction of the left atrium, pulmonary veins, and esophagus compared with the 'true anatomy' on multislice computed tomography in patients undergoing catheter ablation of atrial fibrillation. Heart Rhythm, 3: 317–327.
5. **Hodges G, Bang N, Torp-Pedersen C *et al.* (2020):** Significance of early recurrence of atrial fibrillation after catheter ablation: a nationwide Danish cohort study. J Interv Card Electrophysiol., 60: 271-278.
6. **Vaishnav S, Levine E, Coleman M *et al.* (2020):** Early recurrence of atrial fibrillation after pulmonary vein isolation: a comparative analysis between cryogenic and contact force radiofrequency ablation. J Interv Card Electrophysiol., 57: 67–75.
7. **Mujovic N, Marinkovi M, Markovi N *et al.* (2018):** The relationship of early recurrence of atrial fibrillation and the 3-month integrity of the ablation lesion set. Sci Rep., 8: 313-319.
8. **Kranert M, Shchetynska-Marinova T, Liebe V *et al.* (2020):** Recurrence of atrial fibrillation in dependence of left atrial volume index. *in vivo,* 34 (2): 889-896.
9. **Xue Y, Wang X, Thapa S *et al.* (2017):** Very early recurrence predicts long-term outcome in patients after atrial fibrillation catheter ablation: a prospective study. BMC Cardiovascular Disorders, 17 (1): 1-7.
10. **Liu F, Song T, Hu Q *et al.* (2023):** Body mass index and atrial fibrillation recurrence post ablation: A systematic review and dose-response meta-analysis. Frontiers in Cardiovascular Medicine, 9: 878-886.
11. **Jiamsripong P, Honda T, Reuss S *et al.* (2008):** Three methods for evaluation of left atrial volume. European Journal of Echocardiography, 9 (3): 351-355.
12. **Stöckigt F, Eberhardt F, Horlitz M (2019):** Complication prevention in ablation procedures: How to perform transseptal puncture safely in case of atrial septum aneurysm. Heart Rhythm Case Reports, 5 (11): 529-533.
13. **Galal A, Amin M, Allam L *et al.* (2019):** Assessment of cardiac autonomic dysfunction after pulmonary vein isolation and its impact on success of paroxysmal atrial fibrillation ablation. Ain Shams Medical Journal, 70 (7): 523-541.
14. **Havranek S, Fiala M, Bulava A *et al.* (2016):** Multivariate analysis of correspondence between left atrial volumes assessed by echocardiography and 3-dimensional Electroanatomic mapping in patients with atrial fibrillation. PLoS One, 11: 64-73.
15. **Kim G, Shim J, Kim H *et al.* (2018):** Characteristics of atrial fibrillation patients suffering atrioesophageal fistula after radiofrequency catheter ablation. J Cardiovasc Electrophysiol., 29: 1343–1351.
16. **Lip Y, Lane A (2015):** Stroke prevention in atrial fibrillation: a systematic review.JAMA, 313 (19): 1950–1962.
17. **Kim Y, Kim G, Choi I *et al.* (2021):** A novel predictive model for late recurrence after catheter ablation for atrial fibrillation using left appendage volume measured by cardiac computed tomography. Int J Cardiovasc Imaging, 10: 1007-1018.
18. **Potpara T, Dagres N, Arbelo E *et al.* (2021):** 2020 ESC guidelines for the diagnosis and management of atrial fibrillation developed in collaboration with the european

Association of Cardio-Thoracic Surgery (EACTS). Eur. Heart J., 42: 373-498.

19. **Mozaffarian D, Benjamin J, Go S *et al.* (2015):** Heart disease and stroke statistics—2015 update: a report from the American Heart Association. Circulation, 131: 29–34.
20. **Haissaguerre M, Jais P, Shah C *et al.* (1998):** Spontaneous initiation of atrial fibrillation by ectopic beats originating in the pulmonary veins. N Engl J Med., 339: 659–666.
21. **Njoku A, Kannabhiran M, Arora R *et al.* (2018):** Left atrial volume predicts atrial fibrillation recurrence after radiofrequency ablation: a meta-analysis. Europace., 20: 33-42.
22. **Lizewska-Springer A, Dabrowska-Kugacka A, Lewicka E (2018):** Echocardiographic predictors of atrial fibrillation recurrence after catheter ablation: A literature review. Cardiol J., 27 (6): 848-56.
23. **Sato T, Sotomi Y, Hikoso S *et al.* (2022):** DR-FLASH Score Is Useful for Identifying Patients With Persistent Atrial Fibrillation Who Require Extensive Catheter Ablation Procedures. Journal of the American Heart Association, 11 (16): 744-751.
24. **Škňouřil L, Havránek Š, Bulková V *et al.* (2017):** Disparity between two-dimensional echocardiographic and electroanatomic left and right atrial volumes in patients undergoing catheter ablation for long-standing persistent atrial fibrillation. Physiological Research, 66 (2): 241-247.
25. **Ujino K, Barnes E, Cha S *et al.* (2006):** Two-dimensional echocardiographic methods for assessment of left atrial volume. Am J Cardiol., 98: 1185-1188.
26. **Cozma D, Popescu A, Lighezan D *et al.* (2007):** Left atrial remodeling: assessment of size and shape to detect vulnerability to atrial fibrillation. Pacing Clin Electrophysiol., 30: S147–150.
27. **Bisbal F, Guiu E, Calvo N *et al.* (2013):** Left atrial sphericity: a new method to assess atrial remodeling. Impact on the outcome of atrial fibrillation ablation. J Cardiovasc Electrophysiol., 24: 752-759.
28. **Abecasis J, Dourado R, Ferreira A *et al.* (2009):** Left atrial volume calculated by multi-detector computed tomography may predict successful pulmonary vein isolation in catheter ablation of atrial fibrillation. Europace., 11: 1289–1294.
29. **Marchese P, Malavasi V, Rossi L *et al.* (2012):** Indexed left atrial volume is superior to left atrial diameter in predicting nonvalvular atrial fibrillation recurrence after successful cardioversion: A prospective study. Echocardiography, 29 (3): 276-284.
30. **Von Bary C, Dornia C, Eissnert C *et al.* (2012):** Predictive value of left atrial volume measured by non-invasive cardiac imaging in the treatment of paroxysmal atrial fibrillation. J Interv Card Electrophysiol., 34: 181–188.
31. **Rabbat G, Wilber D, Thomas K *et al.* (2015):** Left atrial volume assessment in atrial fibrillation using multimodality imaging: a comparison of echocardiography, invasive three-dimensional CARTO and cardiac magnetic resonance imaging. Int J Cardiovasc Imaging, 31: 1011-1018.
32. **Sawhney N, Anousheh R, Chen W *et al.* (2010):** Circumferential pulmonary vein ablation with additional linear ablation results in an increased incidence of left atrial flutter compared with segmental pulmonary vein isolation as an initial approach to ablation of paroxysmal atrial fibrillation. Circ Arrhythm Electrophysiol., 3: 243–248.
33. **Nalliah J, Lim W, Kizana E *et al.* (2015):** Clinical significance of early atrial arrhythmia type and timing after single ring isolation of the pulmonary veins. Europace., 17: 1038–1044.
34. **Ukita K, Egami Y, Kawamura O *et al.* (2021):** Clinical impact of very early recurrence of atrial fibrillation after radiofrequency catheter ablation. Journal of Cardiology, 78 (6): 571-576.
35. **Marijon E, Fazaa S, Narayanan K *et al.* (2014):** Real-time contact force sensing for pulmonary vein isolation in the setting of paroxysmal atrial fibrillation: procedural and 1-year results. Journal of Cardiovascular Electrophysiology, 25: 130–137.