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ORIGINAL PAPER

Left atrial anterior line ablation using ablation index and inter-lesion distance measurement

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Abstract

Background Ablation index (AI) is a novel ablation quality marker that incorporates contact force (CF), time and power in a weighted formula to provide accurate information about lesion formation during catheter ablation. This index has been evaluated for pulmonary vein isolation (PVI) but has not been systematically used for other left atrial (LA) procedures so far. The aim of this study is to evaluate the feasibility and efficacy of this index for LA anterior line (AL) ablation (LAALA).

Methods 30 consecutive patients with persistent atrial fibrillation or LA macro-reentrant tachycardia and large low-voltage area at the left atrial anterior wall were evaluated and divided into 2 groups: group 1 (15 pts) LAALA guided by CF; group 2 (15 pts) LAALA guided by AI target (500) and inter-lesion distance ≤ 6 mm.

Results In group 2, shorter ablation time (12.5 ± 3.8 vs 17 ± 7 min, $p = 0.049$), overall RF application time (7.9 ± 1.4 vs 10.8 ± 3.2 min. $p = 0.01$) and less radiofrequency (RF) applications (14.5 ± 2.3 vs 20.5 ± 6.1 $p = 0.01$) were necessary to achieve AL bi-directional block. Acute reconnection of the AL was documented in three patients (20%) of group 1 and in no patient of group 2 (20% vs 0% $p = 0.22$). At site of reconnection, an inter-lesion distance > 6 mm was always found. There was no difference in terms of CF and power between group 2 and group 1. AI was statistically different between group 2 and group 1 ($AI = 511 \pm 77$ vs 451 ± 111; $p = 0.004$).

Conclusion AI-guided LAALA in this study was feasible and featured by shorter ablation time, shorter overall RF application time and a reduced number of RF applications to achieve AL bidirectional block.

Keywords Ablation · Ablation index · Anterior line · Contact force · PVI · Pulmonary vein isolation · RF · Power

Introduction

Durable conduction block across deployed myocardial lesions is mandatory not only for pulmonary vein isolation (PVI) but also for any other cardiac ablation strategy [1]. Despite significant improvements in RF ablation technologies (optimized cooling capacity and force sensing capability [2, 3]), long-term efficacy of ablation of linear and contiguous lesions is still limited [4–6]. Therefore, further improvements are still desirable to create durable lesions and prevent interposed gaps with only transiently impaired electrical conduction. Power and contact force are major determinants of sufficient lesion creation and several efforts have been made in the past to improve these two factors [7, 8].

In the absence of real-time assessment of lesion development and transmurality, surrogate measures of lesion quality are commonly utilized, such as impedance drop during ablation [9, 10]. More recently, force–time integral (FTI), a formula which multiplies contact force by radiofrequency application duration, has been used during PVI procedures [4]. However, FTI does not take into account power delivery, an important factor for lesion formation.

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Ablation index (AI) (CARTO 3 V4, Biosense Webster, Inc., Diamond Bar, CA) is a novel marker of lesion quality that incorporates contact force (CF), time (t) and power (P) in a weighted formula ($k*\zeta^{t}{}_{0}\mathrm{CF}^{a}(\tau)P^{b}(\tau)\mathrm{d}\tau)^{c}$. AI has been shown to accurately estimate lesion depth in animal studies [11] and recently the prospective use of AI during PVI procedures has shown promising results [12]. However, no study systematically investigated the utility of AI for ablation at other anatomical structures within the left atrium (LA) apart from PVs.

Thus, the aim of this study was to evaluate the feasibility and efficacy of AI-guided LA anterior line ablation (LAALA).

Methods

A total of 30 consecutive patients with drug-refractory persistent atrial fibrillation (AF) large low-voltage area at the left atrial anterior wall or left atrial macro-reentrant tachycardia (LAMRT) that underwent LAALA were included in this retrospective analysis. AF was defined persistent if episodes lasted > 7 days or required electrical or pharmacological cardioversion after ≥ 48 h from onset [13]. LAMRT was defined as follows: (1) continuous sequence of atrial activation, with the earliest activation adjacent to the latest activation, and (2) range of activation times 90% of the tachycardia cycle length [14]. Furthermore, entrainment mapping was performed to identify the reentrant circuit and its critical isthmus.

AI was assessed and evaluated during LAALA ablation only.

All patients were ablated at St. Georg-Asklepios Klinik, Hamburg, Germany. Written informed consent was obtained from each patient for the procedure. The current study complies with the Declaration of Helsinki and was approved by the local ethical committee (WF30/18).

Transesophageal echocardiography was performed prior to ablation to rule out LA thrombi in all patients. All procedures were performed on uninterrupted oral vitamin K anticoagulants with a target INR of 2.0–3.0 on the day of the procedure. If a non-vitamin K anticoagulant was used, its intake was discontinued 24 h before ablation. Catheter ablation was performed under deep sedation with bolus of midazolam and fentanyl and a continuous infusion of propofol. A 6F diagnostic catheter was inserted into the coronary sinus (CS-d) via the right femoral vein. Double trans-septal puncture (TSP) using 8.5F SL1 sheaths (SJM, St. Paul, Minnesota, USA) and a modified Brockenbrough technique was performed as previously described in detail [15]. After, double-TSP unfractionated heparin was administered according to the patient's weight to maintain an activated clotting time (ACT) ≥ 300 s.

Map acquisition

Voltage maps and/or activation maps were created during sinus rhythm or LAMRT applying a 3D electro-anatomic mapping system (Carto Biosense Webster, USA). In patients with persistent AF, sinus rhythm was restored by transthoracic direct electrical cardioversion at the beginning of the procedure. For the LA voltage map, the bipolar voltage reference interval was set between 0.05 and 0.5 mV. The definition of low-voltage area included one of the two following criteria: (1) absence of voltage or a bipolar voltage amplitude ≤ 0.05 mV indistinguishable from noise; (2) low-voltage "abnormal" areas were defined as an amplitude ≤ 0.5 mV, as previously reported [16].

Ablation procedure

Ablation was performed with an open-irrigated tip catheter (Thermocool Smart-touch SF D-curve, Biosense Webster, Diamond Bar, CA, USA). After reconstruction of the LA, each PV ostium was identified by selective PV angiography. In patients with persistent AF, circumferential ablation of the ipsilateral PVs was performed to isolate the PVs; in patients with redo-procedures, re-isolation of the PVs was performed in case of previous pulmonary vein isolation (PVI). Afterwards in patients with persistent AF and evidence of large low-voltage area at the left atrial anterior wall, LAALA was performed. Patients with LAMRT were primarily treated with LA anterior line linear ablation.

Anterior line ablation started from the mitral valve and ended at the antero-superior aspect of the right superior PV. Irrigated radiofrequency (RF) was delivered, targeting a maximum temperature of 43 °C, a maximum power level of 35 W and an infusion rate of 20 ml/min. Along the anterior wall, the maximum power was limited to 30 W.

Patients were divided into two groups according to the ablation protocol. In patients of group 1 ($n = 15$), lesion creation was guided by Contact Force targets of 10–40 g, aiming for local signal attenuation of ≥ 80% at each point [17, 18]. Ten procedures of the first group were used to calculate an individual AI for LAALA (AI = 500 with 30 W). However, the performing physician was blinded to AI values.

In patients of group 2 ($n = 15$), all procedures were guided by AI target values for LAALA (AI = 500) and targeting an inter-lesion distance ≤ 6 mm (Fig. 1).

All procedures have been performed by a single highly experienced operator.

Conduction block along the anterior line was validated during sinus rhythm by (1) an abrupt prolongation of

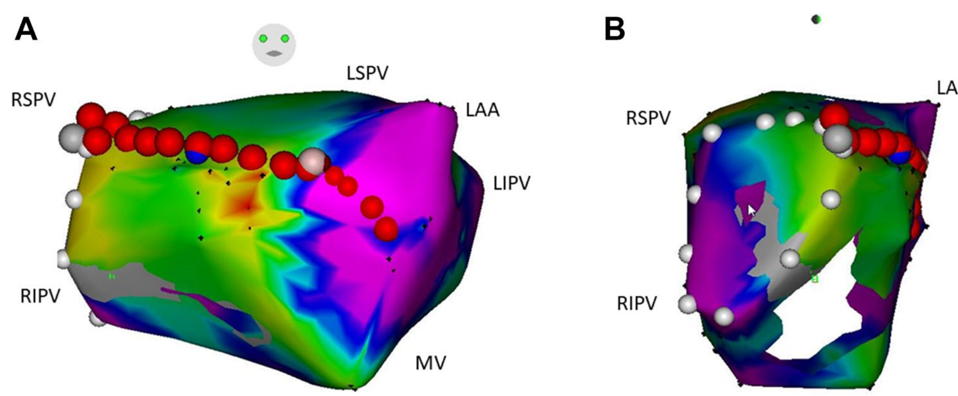

Fig. 1 Voltage 3D map of the left atrium (**a** antero-posterior view, **b** right lateral view) after ablation of a LA anterior line in a patient of group 2 with perimitral flutter. Red points are those where an ablation index of more than 500 was reached. Blue point is where LA anterior line was blocked. *RSPV* right superior pulmonary vein, *RIPV* right inferior pulmonary vein, *LSPV* left superior pulmonary vein, *LIPV* left inferior pulmonary vein, *LAA* left atrial appendage, *MV* mitral valve

conduction time into the LAA of at least 50 ms (2) early signals at the sites preceding the line and late after (3) widely spread double potentials along the whole line with pacing at either side of the line, (4) differential pacing maneuvers [19].

Statistical methods

Continuous variables are reported as means ± standard deviation and compared with Student's *t* test for unpaired groups as required, and dichotomic variables as percentage and compared with χ^2 test of Fisher test as required. A *p* value < 0.05 was considered as statistically significant.

Results

Baseline characteristics

Thirty consecutive patients (56% male), mean age 72 ± 5 years, were referred for left atrial ablation procedures (80% with persistent AF and 20% with LAMRT as index arrhythmia). Mean left ventricular ejection fraction was 56 ± 9% and left atrial volume was 126 ± 35 ml. All the patients presented at left atrial voltage map a large low-voltage area at the LA anterior wall, involving more than 50% of anterior wall without significant low-voltage areas in other LA regions. Groups 1 and 2 did not differ significantly in terms of age, sex and cardiovascular risk factors. Baseline characteristics are reported in Table 1.

Procedural data

Ablation time to achieve AL bi-directional block was shorter in patients of group 2 (12.5 ± 3.8 vs 17 ± 7 min; $p = 0.049$); moreover, patients of group 2 required less RF applications (14.5 ± 2.3 vs 20.5 ± 6.1 $p = 0.01$) and RF application time required for anterior line ablation was significantly shorter between groups 2 and 1 (7.9 ± 1.4 vs 10.8 ± 3.2 min. $p = 0.01$) (Fig. 2). LAMRT terminated during LAALA in all the procedures. No complications were recorded in any patient.

At the end of the procedure after 30-min waiting period, acute AL reconnection was documented in three patients (20%) of group 1 and in no patient of group 2 (20% vs 0% $p = 0.22$).

At sites of early reconnection, AI was 600, 510 and 440, respectively. However, in all three patients inter-lesion distance was > 6 mm (7, 8, 9.3 mm).

Evaluation of depth and contiguity lesion criteria

When comparing ablation parameters during LAALA of group 2 vs group 1, there was no difference in terms of average contact force (24.8 ± 13 vs 22.4 ± 14 g; $p = 0.14$) and maximal power (27.8 ± 4.7 vs 28.4 ± 4.6 W; $p = 0.19$). However, in patients of group 2, RF time per application was reduced (16.3 ± 13.6 vs 24.7 ± 11.2 s; $p = 0.001$). No significant difference in terms of rate of impedance drop between the groups was found (9.4% vs 9.2% $p = 0.78$) (Table 2; Fig. 3).

Ablation index was statistically different between groups 2 and 1 (AI = 511 ± 77 vs 451 ± 111; $p = 0.004$). Moreover, patients of group 2 had a reduced force–time integral (363 ± 267 vs 597 ± 501 g/s $p = 0.001$).

No significant differences between groups 2 and 1 were present in terms of inter-lesion distance (5.35 ± 2.0 vs 5.25 ± 1.9 mm, $p = 0.61$).

Table 1 Baseline features and intraprocedural findings

	Group 1 (CF guided) 15 pts	Group 2 (AI guided) 15 pts	*P* value
Age (years)	71.9 ± 5.7	73.1 ± 6.3	0.58
Male, *n*	9 (60%)	8 (53%)	0.87
Persistent AF, *n*	13 (86%)	11 (76%)	0.34
1st procedure (PVI + anterior line)	6/13 (46%)	5/11 (46%)	
2nd procedure (rePVI + anterior line)	7/13 (54%)	6/11 (54%)	
LAMRT, *n*	2 (14%)	4 (26%)	0.46
LVEF%	58 ± 5.6	54.5 ± 11.4	0.36
LA volume (ml)	118.8 ± 30	136.2 ± 41.2	0.25
Hypertension, *n*	9 (60%)	10 (66%)	0.65
Previous CVE, *n*	1 (6%)	2 (13%)	0.74
CHA_2DsVAS_2C score	2.8 ± 1.4	3.3 ± 1	0.36
Antiarrhythmic drugs			
Betablockers	10/15 (66%)	11/15 (73%)	0.98
Flecainide	5/15 (33%)	3/15 (20%)	0.68
Amiodarone	2/15 (13%)	2/15 (135)	0.98
Length of LA anterior line (mm)	65.5 ± 7.8	65 ± 8.9	0.89
Time to transition *p* wave/LAA (msec)	190 ± 12	198 ± 21	0.88

AF atrial fibrillation, *AI* ablation index, *CF* contact force, *CVE* cerebrovascular event, *LA* left atrium, *LAMRT* left atrial macro-reentry tachycardia, *LVEF* left ventricular ejection fraction

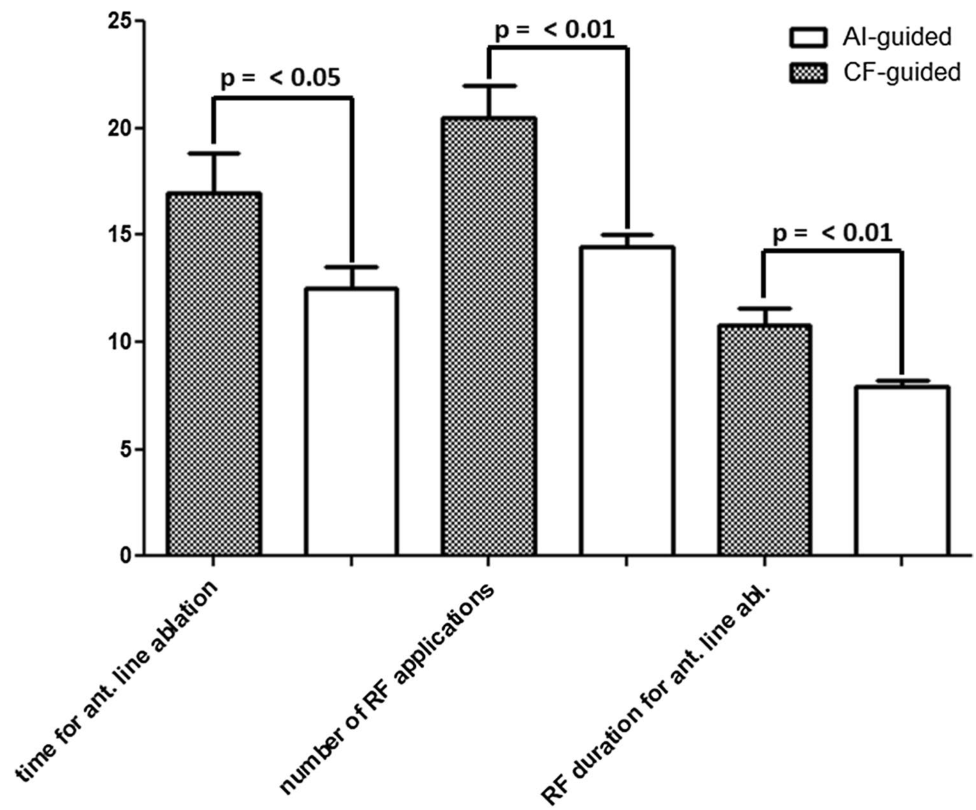

Fig. 2 Procedural data comparing two groups: group 1 contact force (CF) guided and group 2 ablation index (AI) guided. *Ant* anterior, *RF* radiofrequency

Table 2 Parameters of lesion quality in both groups

	Group 1 (CF guided)	Group 2 (AI guided)	*P* value
RF time per application (s)	24.7 ± 11.2	16.3 ± 13.6	**0.001**
Contact force (g)	22.4 ± 14	24.8 ± 13	0.14
Power (watt)	28.4 ± 4.6	27.8 + 4.7	0.19
% Impedance drop	9.4%	9.2%	0.88
Ablation index	451 ± 111	511 ± 77	**0.004**
Force–time integral (g/s)	597 ± 501	363 ± 267	**0.001**
Inter-lesion distance (mm)	5.25 ± 1.9	5.35 ± 2	0.61

CF contact force, *AI* ablation Index

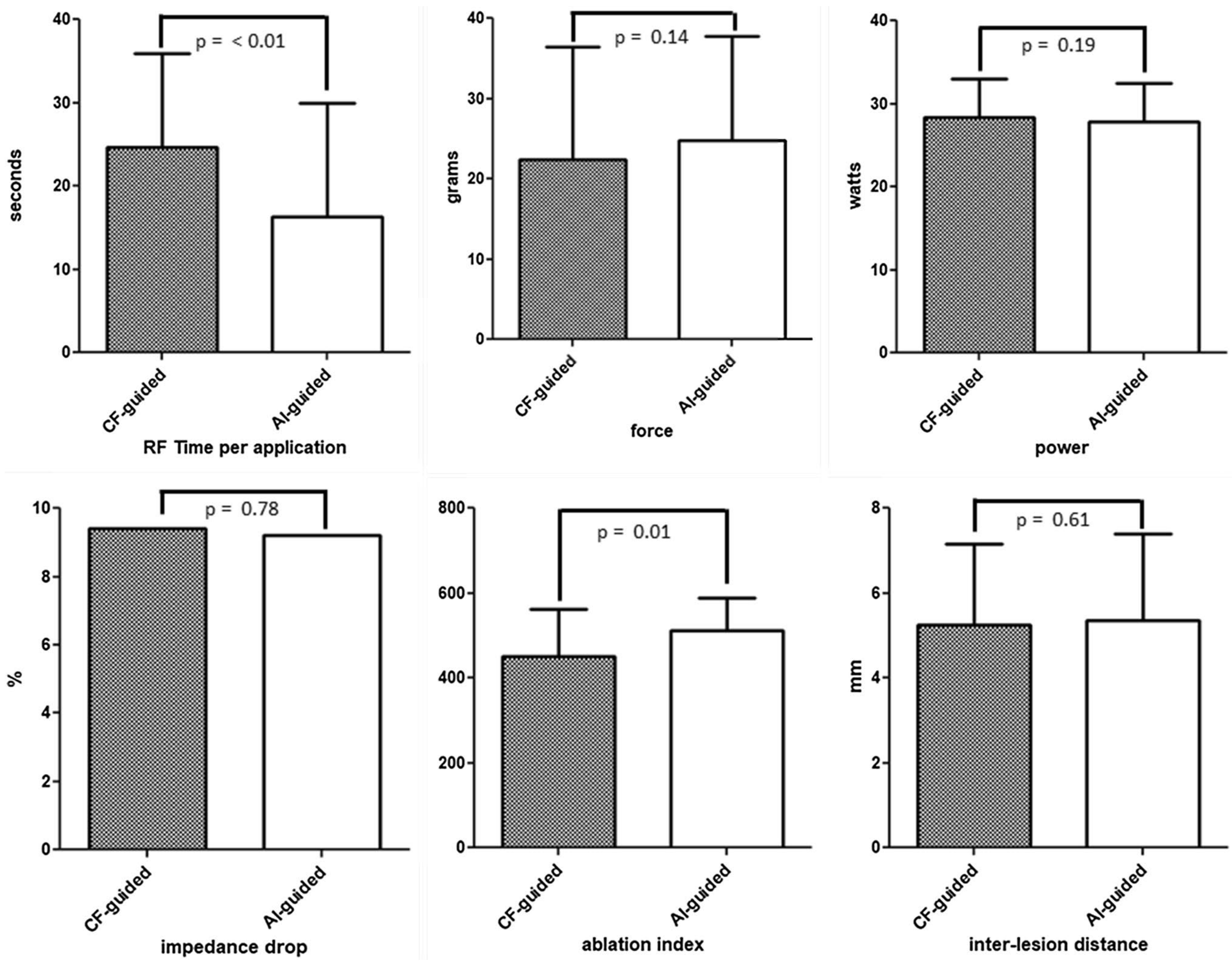

Fig. 3 Comparison of ablation parameters of two groups: group 1 contact force (CF) guided and group 2 ablation index (AI) guided

Discussion

This is the first study systematically evaluating the use of AI for the assessment of myocardial lesion creation with RF to achieve bidirectional block of the left atrial anterior line.

The main findings of this study are

1. bidirectional block of anterior LA line performed with RF applications and guided by ablation index resulted in shorter ablation times and a shorter RF application time;

2. acute reconnection of the anterior LA line during the procedure was found among those areas where inter-lesion distance was more than 6 mm;
3. ablation index may allow to create more durable lesions, with a lower number of RF applications necessary when creating an anterior LA line.

Catheter ablation using ablation index

Radiofrequency ablation is an established treatment for several cardiac arrhythmias. However, in the absence of real-time assessment of lesion creation, there is still a need of indirect parameters to assess for the quality of ablation lesions.

Contact force expressed in grams has been first evaluated. Di Biase et al. found that a contact force above 40 g resulted in a higher risk of steam pops, whereas contact force below 10 g did not result in transmural lesions regardless of the power [18].

Several studies have shown that contact force and time expressed in a formula called FTI (force–time integral) might be able to predict occurrence of gaps within the ablation lines after PVI. In the EFFICAS I study, the site of late PV reconnection (PVR) strongly correlated with minimal CF and FTI. Minimal CF of 20 g and minimal FTI > 400 gs at each PV segment correlated with a 95% probability of durable PV isolation (at 3 months after index procedure) [2]. Similarly, Park et al. showed that a cutoff value of 10 g CF (and a minimum FTI of 400 gs) has a high sensitivity and specificity for acute durability of PVI [20].

However, FTI as a marker of lesion quality has several limitations. First of all, it ignores the role of power delivery in lesion creation [21]. Second, this integral is a simple multiplication of contact force by application time, whereas the relationship between these parameters is dynamic, with both making differing contributions to lesion formation [22].

Ablation index is a novel marker of lesion quality that incorporates contact force, time and power in a weighted formula and has been mainly used for PVI procedures so far [12]. This formula is individual for each operator and provides a value that needs to be fulfilled in different segments of PVs. Das et al. evaluated AI target values for anterior and posterior segments of PVs of 480 and 370, respectively. Application of these regional target values provides a more tailored approach to left atrial ablation by avoiding excessive ablation in higher risk thin-walled areas such as the posterior wall, without compromising on efficacy at areas of thicker tissue such as the PV ridge [23].

AI seems to be a good ablation descriptor and has shown better correlation with impedance drop when compared with FTI. However, the use of the STSF catheter is associated with a lower impedance drop per FTI or AI and an impedance-drop plateau is reached sooner when compared to a conventional smart-touch ablation catheter [24].

Anterior LA wall ablation

Bidirectional block of the anterior line is an approach for treatment of peri-mitral flutter and is a potential additional target for substrate modification in patients with persistent AF and low-voltage areas of the anterior LA wall. Indeed, Pak et al. compared 200 patients with persistent AF, of these 100 receiving anterior line ablations and 100 mitral isthmus line (MI) ablations. They found that at long-term follow-up the recurrence rate of AF after LAALA was significantly lower than that of MI ablation after a single procedure (26% vs 41% $p = 0.02$) [25].

This approach has several potential benefits: (a) conduction block that can be more easily made using LAALA linear ablation compared to MI ablation; (b) better contact pressure can be achieved with LAALA thanks to the contact between anterior wall and the aorta (posterior wall), which is a rigid structure; (c) LAALA reduces the LA critical mass and may block multiloop reentries around the mitral valve annulus, LA appendage, or septum.

Ablation of the anterior line with persistence of bidirectional block also plays a role for completion of wide-area left atrial appendage electrical isolation which has shown to reduce recurrence of atrial tachyarrhythmias in selected patients [26]. Actually, in the context of persistent AF ablation, additional ablation of other areas than PVs (lines, rotors or fractionated signals) did not prove significant benefit in terms of AF freedom [27, 28].

In the present study's population, to create a substrate modification in patients with large anterior LA low-voltage area, an oblique anterior line coursing from the mitral valve annulus (MVA) to the right superior pulmonary vein (RSPV) has been performed. However, some groups use a shorter vertical line from the MVA to the left superior pulmonary vein (LSPV) with good results at long-term FU [29].

In the present study, bidirectional block of the anterior line guided by ablation index resulted in shorter procedure times and a lower number of RF applications as well as shorter RF application times. These results are in line with the CLOSE protocol where fifty consecutive paroxysmal AF patients underwent PVI targeting an ILD ≤ 6 mm and an AI ≥ 400 (posterior) and ≥ 550 (anterior) and were compared with 50 patients where ablation was performed with a conventional CF-guided approach. In the 'CLOSE' group, procedure times and RF times per circle were shorter (respectively, 149 ± 33 min vs 192 ± 42 min, $p < 0.0001$ and 18 ± 4 min vs 28 ± 7.5 min, $p < 0.0001$) [30].

In line with these data, in the present study, acute reconnection sites were found in those areas where inter-lesion distance was > 6 mm. Indeed, the main reasons for reconnection are lesion depth and lesion contiguity. When the lesion depth is reached, the main predictor of recurrence is the inter-lesion distance and vice versa [31]. In the CLOSE study, 100% of recurrence sites were found among those sites where ILD was > 6 mm [24].

Interestingly, in the present study, LAALA AI-guided procedures were featured by reduced RF time per application (16.39 ± 13.69 vs 24.77 ± 11.20 s $p = 0.001$) and this is reflected in a reduced FTI in the AI group. However, although not statistically different, in the AI group, a trend to higher contact force values was seen (24.8 ± 13 vs 22.4 ± 14 g $p = 0.14$).

As previously shown by Chun et al., PVI plus linear lesion when compared with PVI only is featured by higher risk of cardiac tamponade (3.2% vs 0.5% $p = < 0.01$) [32]. The optimization of ablation time combined with contact force and power could be helpful to avoid complications in these high-risk procedures. Therefore, ablation index could be a useful tool in this context.

Limitations

This is a retrospective single-center study with a limited number of patients. Larger cohorts and multi-center studies are needed to validate these data. During ablation of contact force group patients, a subgroup ($n = 10$ pts) was used for AI calculation. This might be a potential bias, as a training effect cannot be ruled out. Computer tomography or cardiac magnetic resonance imaging was not performed before or after the procedure to evaluate directly left atrial wall thickness before ablation and myocardial lesion after ablation.

Conclusion

AI-guided ablation of left atrial anterior line is feasible and featured by shorter ablation times and a lower number of RF applications. AI-guided LAALA may allow to achieve better lesion quality, with a reduction of RF application time in case of adequate contact and power.

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