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Two Year, Single Center Clinical Outcome After Catheter Ablation For Paroxysmal Atrial Fibrillation Guided by Lesion Index

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Abstract

Background: This study describes the use of lesion index (LSI) as a direct measure to assess the adequacy of ablation lesion formation with force-sensing catheters in ablation of paroxysmal atrial fibrillation (PAF). LSI is calculated by the formula:LSI = CF (g) ×Current (mA) ×Time (sec).

Methods: Fifty consecutive patients with PAF underwent pulmonary vein (PV) isolation using a catheter dragging technique and targeting different LSI values in different anatomical areas.A force-sensing ablation catheter was used to continuously measure contact force (CF) and guide radiofrequency ablation (RF) lesion formation. Ablation lesions were delivered to achieve an LSI value of 5.0 in posterior locations, 5.5 in anterior locations and 6.0 in the region between the left atrial appendage and left superior pulmonary vein ridge. Force-time Integral (FTI) was not used to evaluate lesion formation.

Results: A single center, retrospective analysis was performed with 196/198 (99%) PVs acutely isolated. The mean procedure time was 134 ± 34 mins and the mean fluoroscopy time was 7.8 ± 3.2 mins. At a mean follow up of two years, 43/50 (86%) of patients were in normal sinus rhythm with no documented recurrences of atrial fibrillation.

Conclusion: LSI can be used to guide the placement of durable lesion formation with RF ablation using CF catheters in patients with PAF.

Introduction

Contact force(CF) sensing catheters have recently been introduced and shown to be an effective tool for increasing the success of ablation for paroxysmal atrial fibrillation (PAF)[1 ,2]. Prior to the introduction of these catheters, indirect measures such as drop in impedance, electrode temperatures, and changes in electrogram morphology were used to assess the adequacy of the lesion delivered[3,4,5,6]. Based primarily on the EFFICAS I and EFFICAS II studies, the primary direct metric that is most commonly used to evaluate adequate lesion formation with radiofrequency (RF) energy is the Force Time Integral (FTI). FTI is a combination of Force and Time[7,8]. FTI, however, does not take into account power delivery. Further more, most studies apply a FTI value of 400 gs to all segments of the left atrium (LA) even though anatomical studies have shown that the tissue thickness varies considerably between different regions in the LA[9,10]. Lesion Index (LSI)is another measure that can be used to guide RF lesion formation[11,12]. LSI is calculated using CF, RF application duration, and RF current. LSI has been used in preclinical studies and in human studies with short term follow up[13,14,15]. Long term clinical outcome data using LSI, however, has not been reported. This single center, retrospective study reviews the two-year clinical outcomes after pulmonary vein isolation (PVI) using a CF sensing 3.5mm irrigated ablation catheter (TactiCath Quartz, Abbott Laboratories, Abbott Park, IL, USA),with lesion formation guided by LSI.

Key Words

Ablation, Atrial Fibrillation, Lesion Index

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Material and Methods

Calculations

FTI is a calculated by the formula: Contact Force (g)× Time (s). The result is expressed in gram seconds (gs) and the result is a linear relationship. LSI, contrastingly, is a non-linear estimate of lesion growth using CF, duration of the lesion and RF current. Use of Current is the main differentiating factor between LSI and FTI. LSI is calculated as a complex weighted, exponential formula assigning different weights to CF, current and time. Each sub component is nonlinear and is expressed as a negative exponential, which accounts for the transition from resistive heating to thermal conduction. LSI is expressed by the formula: LSI = CF (g)×Current (mA)×Time (sec)

All 3 sub components are proportional to $(1\text{-}e^{(-t/\tau)})$. e is the exponential constant, t is time and τ is the time constant. The result is the amount of energy that is delivered[16].

Inclusion and Exclusion

Fifty consecutive patients with symptomatic, drug refractory PAF that were refractory to Class I or III antiarrhythmic drug (AAD) were admitted for atrial fibrillation (AF) ablation. For all patients, this was their de novo LA ablation procedure. All patients were anticoagulated with a Novel Oral Anticoagulant (NOAC) or therapeutic warfarin, for four weeks prior to the ablation. In addition, all patients that were in AF at the time of ablation underwent a transesophageal echo prior to the case to evaluate for thrombus. A preprocedural CT scan was performed to evaluate the pulmonary vein (PV) and left atrial anatomy. Exclusion criteria included persistent atrial fibrillation (pAF), history of prior catheter or surgical ablation of the LA, presence of a left atrial thrombus or contraindications to oral anticoagulation, myocardial infarction within three months, and severe pulmonary disease.

Intraprocedural Care

Patients were brought into the cardiac electrophysiology laboratory in a fasting state. Antiarrhythmic medications were discontinued at least 48 hours prior to the procedure. Discontinuation of anticoagulation was at the discretion of the operator. All procedures were performed under general anesthesia. Intracardiac echo was employed for imaging for transseptal access. Heparin was infused to achieve an activated clotting time (ACT) of greater than 300 seconds prior to accessing the LA. A continuous infusion of heparin was employed to maintain the ACT between 300s and 350s. A decapolar coronary sinus (CS) catheter (LiveWire, St. Jude Medical, St. Paul, MN, USA) was advanced into the CS and shadowed to maintain a stable reference throughout the case. Two separate transseptal punctures were performed. Two sheaths, a fixed sheath (Daig SL-1, Abbott Laboratories, Abbott Park, IL, USA) and a steerable transseptal sheath (Agilis, Abbott Laboratories, Abbott Park, IL, USA) were inserted into the LA.

Using the impedance based electroanatomic 3D mapping system (Ensite Velocity, Abbott Laboratories, Abbott Park, IL, USA) geometry of the LA and PVswere acquired using a circular mapping catheter (Reflexion Spiral, Abbott Laboratories, Abbott Park, IL, USA). This geometry was displayed along with the anatomy from the CT that was acquired prior to the ablation. An esophageal temperature probe (Level 1 Acoustascope 12 French, Smiths Medical ASD, Inc., St. Paul, MN) was placed and monitored for changes. The esophageal temperature probe was moved inferiorly and superiorly to mirror the location of the ablation catheter. Any increase in temperature was noted and an increase of more than 1.0^{c} led to discontinuation of ablation in that region. Phrenic nerve activity in the right sided veins was evaluated with high output pacing from the Reflexion Spiral in the antrum of the veins. Ablation lesions were delivered via an Ampere RF generator (Abbott Laboratories, Abbott Park, IL, USA) to achieve energy up to 25-35W with a maximum temperature of 42C in each location. Lesions in the posterior LA were limited to 25-30W while lesions in the anterior wall were delivered at 35W. A wide area, antral ablation lesion set was delivered. Lesions were confined to isolation of the PVs. Additional ablation lesions such as a roof line, mitral isthmus line, Complex Fractionated Atrial Electrogram (CFAE), substrate mapping and right atrial cavotricuspid isthmus line were not performed in the study group. At the completion of the ablation, entrance and exit block was demonstrated with all pulmonary veins. In addition, Adenosine (6-18mg) was infused to evaluate PV activity. If there was an increase in PV activity associated with adenosine, further ablation lesions were delivered in the target sites. Adenosine testing was repeated until there was no further activity. At the completion of the case, all patients were in sinus rhythm.

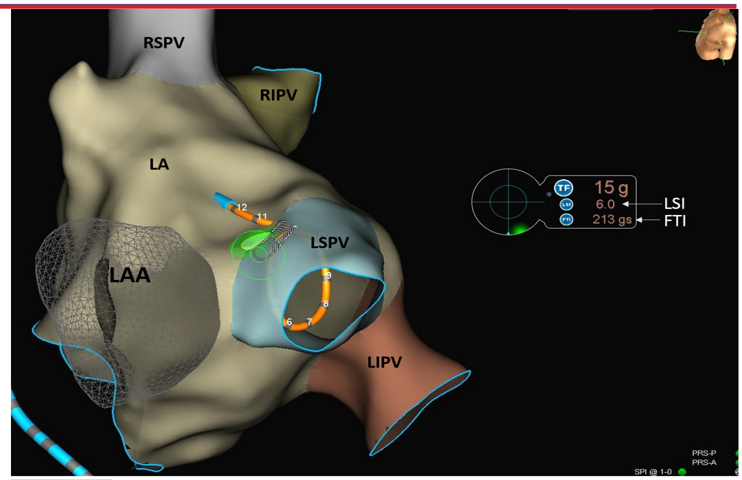

Figure 1: Left Anterolateral view of the Left Atrium(LA). The ablation catheter is contacting the tissue between the Left atrial appendage(LAA) and the Left superior pulmonary vein(LSPV). In this location,an ablation lesion with an LSI value of 6.0 delivered.Contact Force(TF), Lesion Index (LI), Force Time Integral (FTI), Left inferior pulmonary vein (LIPV), Right superior pulmonary vein (RSPV), Right inferior pulmonmary vein(RIPV).

LSI

Based on prior pre-clinical and clinical studies, the lesion index (LSI) was used to guide the duration of each ablation lesion[11-15]. An LSI value of 5.0 was targeted in posterior locations and 5.5 in anterior locations. A higher value of 6.0 was targeted aroundleft atrial appendage (LAA) – left superiorpulmonary vein (LSPV) ridgebecause of increased thickness of the tissue in this area[17].[Figure 1] and [Figure 2]. When the LSI value was achieved, the catheter was moved to the next location. The majority of lesions were delivered with a continuous drag method. In areas where catheter stability was difficult, focal lesions were placed without dragging. The value for LSI was recalculated with every new catheter location. Lesions were delivered with a minimum CF of 10gm and a maximum CF of 40gm. If the CF was out of range or the lesions were not contiguous, the

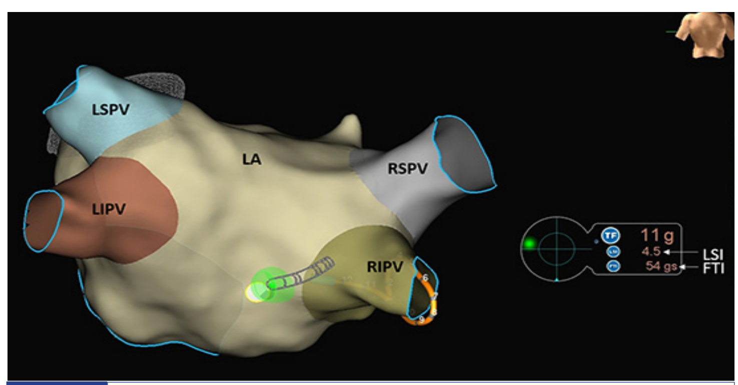

Figure 2: Posterior view of the Left Atrium (LA). The ablation catheter is contacting the issue on the posterior wall. In this loacation, anablation lesion with an LSI of 4.5 was delivered enroute to a total LSI value of 5.0.Contact Force (TF), Lesion Index (LI), Force Time Integral (FTI), Leftinferior pulmonary vein(LIPV), Right superior pulmonary vein (RSPV), Right inferior pulmonmary vein (RIPV).

catheter position was adjusted until the CF was in range. FTI data was not used for lesion evaluation.

Post Procedural Care

All patients were observed overnight and discharged home the next day. All antiarrhythmic medications were discontinued by the end of the three month blanking period. After the three month blanking period was completed, all patients wore a two week continuous monitor capable of detection of asymptomatic episodes of AF. In accordance with the Heart Rhythm Society (HRS) guidelines, all patients were followed for two yearswith ECGs and Holter monitors for documentation of any symptomatic episodes[18]. Anticoagulation was continued at least three months and then guided by the individual patient's CHA_2DS_2-VASc score.

End Points

The primary end point was AF recurrence, defined as a documented episode of AF >30 seconds, either symptomatic or asymptomatic on an event monitor or an ECG. Secondary endpoints were procedural related complications such as pericardial effusion with tamponade physiology, cerebral embolism, groin hematomas, pericarditis and atrioesophageal fistula formation.

Table 1: Patient characteristics

DATA	RESULTS Study Cohort
Age	61±9
Male	34 (79)
LVEF	13 (30)
LA Size	2 (4.7)
CHA_2DS_2-VASC Score	2 (4.7)
DM	4 (8%)
HTN	14 (28%)
CAD	10 (20%)
CHF	1 (2%)
Flouroscopy Time (mins)	7.8 (±3.1)
Total Procedure Time (mins)	134 (±35)

Results

A total of 50 patients were enrolled (43 men and 7 women,mean age 60+8.7, LA Volume 29.3+9.5mL). 14 (28%) had hypertension, 10 (20%) with stable coronary artery disease, 4 (8%) with diabetes mellitus. The meanCHA_2DS_2-VASc score was 0.9 (±1.0).[Table 1].

Ablation Results

In this cohort of 50 patients, 198 individual PVs were evaluated (49 RSPV, 49RIPV's, 1 common right sided vein, 49 LSPV's, 49LIPV's, 1left common vein). A total of 196 of 198 veins were acutely isolated using the LSI value to determine lesion placement. 2/198PVs were not isolated and were both LSPVs. The mean procedure time was 134 + 34 mins and the mean fluoroscopy time was 7.8+3.2 mins. LSI did not affect the overall procedure time of 130 mins which is in line with previously reported trials of ablation of PAF. The fluoroscopy time is also similar to what has been described[19].

Clinical Follow Up

At the one year follow up period, 90% (45/50) patients were in normal rhythm. At the end of the two year follow up period, 86% (43/50) of patients were in normal rhythm with no documented recurrences of AF. The two patients that had pulmonary veins that were not isolated did not have recurrences of atrial fibrillation.

Of the seven patients that did have recurrence of AF, five chose to undergo a repeat ablation procedure. Of those five patients, four had vein reconnection in the anterior portion between the superior portion of the LAA and the LSPV. The fifth patient had the recurrent focus in the region between the LAA and the LIPV. All five patients PVs were successfully re-isolated during the repeat ablation. Long term follow up for the second procedure with a mean follow up 19+4.7 months shows no recurrence of AF. 2/7 of the patients with recurrent arrhythmias chose medical therapy with antiarrhythmicmedication rather than a repeat ablation procedure[Table 2].

Table 2: Characteristics of Recurrent Patients

Recurrent patient	Months from initial procedure to recurrence	Location of recurrent PV reconnection
1	4	LUPV-LAA
2	11	LUPV-LAA
3	5	LLPV-LAA
4	4	LUPV-LAA
5	27	LUPV-LAA

Complications

A 4.0% (2/50) acute complication rate was observed with both as pericardial effusions with tamponade physiology. Both patients required percutaneous drainage with resolution of the effusion. There were no other complications noted.

Discussion

Lesion Index is a novel measurement that can be used to guide the adequacy of RF ablation lesion formation. LSI is calculated from the variables of current, ablation time and CF. LSI is distinct from FTI in that FTI is calculated by time and CF but does not to take into account current delivery. In animal models, the LSI values correlated strongly with PV isolation success[11]. Initial work in humans has also shown acute success in isolation of PVs. Similar to LSI, Ablation Index (AI) has also recently been introduced as a potential value to measure lesion formation[20]. This is the first study, to our knowledge, that takes LSI into account to describe clinical outcomes in ablation of PAF. This retrospective, single center study shows that LSI can be used clinically to evaluate the adequacy of lesion formation with ablation of PAF.

Use of FTI to guide ablation lesion formation is the most commonly described measure of lesion formation in RF ablation for PVI. FTI, however, has limitations in its clinical utility to guide ablation lesion formation. The EFFICAS I trial showed minimum values that were predictive of PV reconnection. Subsequently, in EFFICAS II, the value was used to guide ablation therapy. Even with this result, approximately 37.5% of patients were found to have reconnected PVs. One of the potential limitations of FTI is that it does not take into account the heterogeneity of the thickness of left atrial tissue[17,21]. Atrial tissue in the anterior and roof segments of the LAhave been shown to be thicker and may require more than 400gs to achieve a full thickness ablation lesion. Contrastingly, atrial tissue in the posterior wall is thinner and may require significantly less than 400gs to achieve a full thickness ablation lesion. Applying an arbitrarily uniform value across all segments of the LA, in particular, the posterior wall, can lead to RF energy reaching extracardiac locations or not achieving a full thickness lesion.

Another area in the LA where the FTI may fall short in determining the lesion placement is in the LAA-LSPV ridge and the posterior wall. The LAA-LSPV ridge location is an area with thick tissue that is difficult to ablate because of catheter stability. Applying a uniform value of 400 gs to a thick region such as this ridge may not lead to a full thickness lesion. By aiming for a higher LSI of 6.0, in this location, a more durable ablation lesion may be achieved. In our study, of the five recurrent patients that had repeat procedures, the most common area of recurrence was the superior portion of the LAA-LSPV ridge. This suggests that a LSI value even greater than 6.0 may be necessary to achieve a durable lesion in this area. However, in the posterior wall of the LA, power is frequently titrated down because of thinner tissue and the proximity of the esophagus. An adequate LSI on the posterior wall can be achieved with a lower power setting and longer ablation time.

Our method of adjusting the LSI with the anatomical location takes these differences into account. For instance (assume, system impedance is 100 ohms)in scenario A, a lesion at 10 grams for 40 seconds achieves an FTI of 400gs. In scenario B, a lesion with 20 grams for 20 seconds also achieves an FTI of 400 gs. If the power delivered in scenario A is 35 Watts (591.6 mA), the lesion created likely is going to be deeper than if power delivered, in scenario B, is 15 Watts (387.3 mA). FTI will not show the difference in these scenarios, as both will have a value of 400gs. LSI, however, will show a difference (since the current is factored in) as the value will be greater in scenario A rather than scenario B.

Additionally, FTI represents the CF accumulated over time; no electrophysiological parameters are taken into account (such as system impedance or RF power delivered). Further, FTI is a bilinear function of CF and time. Consider the case where the CF is fixed during ablation; FTI will increase linearly throughout the entire duration of ablation. It is well-established that lesion growth does not grow linearly, but rather asymptotically (often modeled as a concave exponential function, such as "1 – e (-x)")[22]. In addition to the CF and time, LSI also includes the electrophysiological parameter (current) which can account for patient-dependent factors (such as impedance). The structure of the LSI formula also accounts for the asymptotic behavior of lesion formation.

Finally, the additional component of current delivered in the LSI equation may lead to a more durable ablation lesion and to increase in the clinical success rates at two years. In this retrospective review of a cohort of 50 patients, 86% (43/50) of the patients were in normal rhythm with a mean of two years follow up. This result is higher than previously reported with contact force catheters where the lesion formation was guided by the FTI alone.

Limitataions

The main limitation of this study is that it is a single center, retrospective study with a limited number of patients. In addition, an age and gender match control was not performed. Further studies examining the use of LSI from a prospective method with multiple centers are likely to add additional knowledge to this subject matter. In addition, FTI data was not used for lesion formation so we are unable to correlate the LSI to FTI. Future work should be done to correlate the clinical results of FTI versus LSI in lesion formation.

Conclusion

LSI can guide the duration of the lesion at each ablation location. Based on the location within the LA, the target LSI number will vary. The two-year outcomes, when the LSI is reached at each location, are excellent.

Conflict Of Interest

Drs. Sundaram and Choe are on the speaker's bureau for Abbott Laboratories. In addition, Drs. Sundaram and Choe have received a research grant from Abbott Laboratories, Asia Division to study the genetic basis of Brugada Syndrome in Cambodia. This conflict is not relevant to the article. C. Boorman, N. Mullins, A. Davies and A. Stucky receive salary support from Abbott Laboratories.

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