Biatrial volume ratio predicts low voltage areas in atrial fibrillation

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Funding Information
Jelena Kornej received funding from the Marie Skłodowska-Curie Actions under the European Union’s Horizon 2020 research and innovation program (grant agreement No 838259).

Abstract
Background: Left atrial volume (LAV) and low voltage areas (LVAs) are acknowledged markers for worse rhythm outcome after ablation of atrial fibrillation (AF). Some studies reported the importance of increased right atrial volume (RAV) as a predictor for arrhythmia recurrences in AF patients.

Objective: To investigate association between the LAV/RAV ratio and LVAs presence.

Methods: Patients undergoing first AF ablation were included. LVAs were assessed peri-procedurally using high-density 3D maps and defined as <0.5 mV. All patients underwent pre-procedural cardiovascular magnetic resonance imaging. LAV (biplane) and RAV (monoplane 4-chamber) were assessed prior to ablation, and the LAV/RAV ratio was calculated.

Results: The study population included 189 patients (age mean 63 ± 10 years, 33% women, 57% persistent AF, 22% LVAs). There were 149 (79%) patients with LAV > RAV. In univariable analysis LAV > RAV was associated with LVAs (OR 6.803, 95%CI 1.395–26.514, p = .016). The association remained robust in multivariable model after adjustment for persistent AF, CHA2DS2-VASc score, and heart rate (OR 5.981, 95%CI 1.256–28.484, p = .025). Using receiver operator curve analysis, LAV > RAV (AUC 0.668, 95%CI 0.585–0.751, p = .001) was significant predictor for LVAs. In multivariable analysis, after adjustment for age, persistent AF, and renal function, RAV ≥ LAV was threefold higher in males (OR 3.040, 95%CI 1.050–8.802, p = .04).

Conclusions: LAV > RAV is useful for the prediction of electro-anatomical substrate in AF. LAV > RAV was associated with LVAs presence, while male sex remained associated with RAV ≥ LAV and less LVAs.

Keywords
atrial fibrillation, cardiac magnetic resonance, left atrial size, low voltage areas, right atrial volume

1 | INTRODUCTION

Becoming a cornerstone therapy in many patients with atrial fibrillation (AF),1 in some patients, catheter ablation with circumferential pulmonary vein isolation alone is not enough for sinus rhythm maintenance during follow-up. The arrhythmia recurrences remain an important clinical challenge and require individualized AF treatment plan already before intervention. One major feature reflecting left atrial (LA) remodeling is...
peri-procedural evidence of low voltage areas (LVAs). At least 20%-25% of AF patients have significant LVAs in peri-procedural mapping, which are an important characteristic of AF progression and treatment failure if not treated with additional ablation. Therefore, assessment of LVAs presence before catheter ablation is an important task for the electrophysiologist allowing individually tailored AF ablation therapy.

The LA size is another important parameter of AF progression. The role of the LA volume (LAV) and LA function as surrogate parameters for higher AF burden and LVAs presence are well described. In addition, there is an association between atrial flutter—a right atrial (RA), and AF—a left atrial disease. Several studies described an importance of RA assessment as a prognosis marker in heart failure, pulmonary hypertension, and chronic obstructive pulmonary disease. Diastolic functional changes—as a preliminary stage for AF—appeared to occur earlier in the right chambers suggesting that RA dilatation might be an early marker for atrial remodeling associated with AF initiation. Previous studies reported the importance of increased RA volume (RAV) as predictor for arrhythmia recurrences in AF patients. It was hypothesized that RA is more prone to hemodynamic changes and is a more responsive marker of structural remodeling. However, association between RAV and LVAs and the prediction capability for LAV/RAV ratio is unknown. Therefore, we aimed to investigate the indexed LAV/RAV ratio assessed in cardiovascular magnetic resonance (CMR) imaging and the association with LVAs in patients undergoing AF catheter ablation. We hypothesize that the biatrial ratio is an independent predictor for LVAs presence.

2 | METHODS

The study population was described previously. Briefly, patients presenting for catheter ablation due to symptomatic AF from October 2015 to April 2017 were included in the study. According to current guidelines, AF subtypes were defined as paroxysmal and persistent. Patients with pregnancy, age <18 or >75 years, valvular AF (any valvulopathies >second degree), cancer, acute, or systemic inflammatory diseases, and acute hyperthyreotic state were excluded from the study. The study was approved by the local Ethical Committee (Medical Faculty, University of Leipzig), and patients provided written informed consent for participation.

2.1 | Cardiovascular magnetic resonance

Prior to AF catheter ablation, all patients underwent 1.5 T CMR (Ingenia, Philips Medical) for LA anatomy assessment as previously described. Briefly, LAV was determined using a biplane model based on cine 4- and 2-chamber views, and RAV using a monoplane model based on the cine 4-chamber view. Both volumes were indexed to body surface areas, and the LAV/RAV ratio was calculated before ablation. We defined two subgroups according to the LAV/RAV ratio: (1) LAV is greater than RAV (LAV > RAV), and (2) RAV is equal or greater than LAV (RAV ≥ LAV).

2.2 | Peri-procedural LA mapping and AF ablation

Transseptal access and catheter navigation were performed with a steerable sheath (Agilis, St. Jude Medical, St. Paul, MN). The electro-anatomical mapping was performed in sinus rhythm as described previously. In case of AF at the beginning of the procedure, the arrhythmia was terminated by electrical cardioversion and the mapping was performed in sinus rhythm.

Multielectrode spiral mapping catheters (Reflexion Spiral and Advisor, St Jude Medical [SJM], Saint Paul, MN in NavX Ensite procedures and Carto Lasso, Biosense Webster, Diamond Bar, CA in Carto3 procedures) were used to generate electro-anatomical voltage maps of the LA. The cutoff value for LVAs was defined as bipolar signal amplitude <0.5 mV. Ectopic beats were excluded from the voltage map. The number of points obtained was >1000. In case of AF recurrence during electro-anatomical mapping, only anatomical map was assessed. Then the electro-anatomical mapping was completed in sinus rhythm after PVI, and if still needed, after further cardioversion.

All patients received circumferential ablation lines around the antrum of the ipsilateral pulmonary veins. The ablation catheters (irrigated tip catheter and power of 25–40 W) used in NavX Ensite procedures were TactiCath (St Jude Medical [SJM], Saint Paul, MN) and for Carto3 procedures SmartTouch Thermocool (Biosense Webster, Diamond Bar, CA). End point of catheter ablation was PV isolation, which was verified with a multipolar circular mapping catheter. Additional linear lesions were added between if LVAs were present in this area. To be considered as relevant the LVAs ought to consist of adjacent low-amplitude mapping points, bearing certain additional characteristics such as fragmentation and duration. Finally, the relevance of the LVAs was evaluated by experienced operators based on the mapping point qualities as well as induction of extra-PV macro-reentry tachycardia, in which case additional linear ablation was performed. Patients with small/negligible LVAs dispersedly distributed in LA and not suitable for ablation, who received the PVI only without additional ablation lines, were excluded.

2.3 | Statistical analysis

Data are presented as mean and standard deviation for normally distributed or median (interquartile range, 25th and 75th percentiles) for skewed continuous variables, and as proportions for categorical variables. The differences between continuous values were assessed using an unpaired t-test or the Mann-Whitney, and a χ² test for categorical variables.

Logistic regression analysis was used to identify factors associated with LVAs. We performed three analyses using logistic regression of LVAs presence (Model 1 – unadjusted analysis; Model 2 – adjusted for age and sex; and Model 3 – adjusted for persistent AF, heart rate, and CHA₂DS₂-VASc score).

Receiver operating characteristic curves (ROC) were generated to analyze performance of the LAV/RAV ratio predicting LVAs, with the
area under the curve (AUC) being equivalent to the c-index for determining the predictive value for the parameters. Finally, we compared the c-indices (i.e., areas under the ROC curves) of LAV > RAV and LAV using DeLong’s method. A p-value < .05 was considered statistically significant. All analyses were performed with SPSS statistical software version 26 (SPSS Inc., Chicago).

### RESULTS

#### 3.1 Clinical characteristics of the study population

The study population included 189 patients (mean 63 ± 10 years, 33% women, 57% persistent AF) undergoing their first AF catheter ablation. Clinical characteristics of the study population are summarized in Table 1. Forty-one patients (22%) had LVAs in periprocedural mapping, which required additional substrate modification. We observed LAV > RAV in 149 (79%) patients (26% with LVAs), while 40 (21%) patients had RAV ≥ LAV (5% with LVAs). Patients with LAV > RAV were significantly older, more often females, had a lower estimated glomerular filtration rate, had more often hypertension and more often LVAs (Table 1).
### TABLE 3 Clinical factors associated with RAV ≥ LAV

|                          | Univariable analysis | Multivariable analysisa |
|--------------------------|----------------------|-------------------------|
|                          | OR (95% CI) | p-value | OR (95% CI) | p-value |
| Age                      | 0.946 (0.914–0.978) | .001 | 0.959 (0.919–1.002) | .061 |
| Persistent AF            | 0.552 (0.273–1.115) | .098 | 0.531 (0.237–1.188) | .123 |
| Males                    | 4.462 (1.652–12.046) | .003 | 3.040 (1.050–8.802) | .040 |
| eGFR                     | 1.041 (1.016–1.066) | .001 | 1.018 (0.988–1.050) | .243 |
| CHA2DS2-VASc score       | 0.844 (0.673–1.059) | .143 |                      |        |

Abbreviations: AF, fibrillation; CI, confidence interval; eGFR, estimated glomerular filtration rate; OR, odds ratio.

*aAdjusted for age, sex, persistent AF, and eGFR.

### 3.2 Association of LAV/RAV ratio with LVAs

In univariable analysis logistic regression, LAV > RAV was associated with sixfold risk of LVAs presence (OR 6.083, 95% CI 1.395–26.514, p = .003). In multivariable analysis, after adjustment for CHA2DS2-VASc score, persistent AF, and heart rate, LAV > RAV remained significantly associated with LVAs (OR 5.981, 95% CI 1.256–28.484, p = .025) (Table 2). Using ROC analysis, LAV > RAV showed moderate prediction of LVAs presence (AUC 0.668, 95% CI 0.585–0.751, p = .001) (Figure 1). Comparing the LAV > RAV with LAV (AUC 0.724, 95% CI 0.639–0.809, p < .001) using DeLong’s method, the difference between ROC curves was not significant (p = .353).

### 3.3 Clinical factors associated with RAV ≥ LAV

In univariable analysis, RAV ≥ LAV was associated with younger age (OR 0.946, 95% CI 0.914–0.978, p = .001), male sex (OR 4.462, 95% CI 1.652–12.046, p = .003), and renal function measured as glomerular filtration rate (OR per 1 ml/kg/1.73m² 1.041, 95% CI 1.016–1.066, p = .001, Table 3). In multivariable analysis, the RAV ≥ LAV was 3-fold higher in males (OR 3.040, 95% CI 1.050–8.802, p = .04).

### 4 DISCUSSION

In our study, we investigated the indexed LAV/RAV ratio and its predictive value on the pre-procedural LVAs in patients undergoing AF catheter ablation (Figure 2). We found that LAV > RAV was associated with sixfold risk for LVAs presence. Also, LAV > RAV was less observed in males.

### 4.1 Biatrial ratio as parameter for AF progression and LVAs prediction

The role of RA size in AF pathogenesis is controversial. It had been reported that RAV and the RAV/LAV ratio were predictive for AF recurrence after PVI in patients with persistent AF, while LAV was not.14 Another study confirmed these findings in AF patients after cardioversion.13 Both studies suggested that AF is a biatrial disease, not being exclusively associated with isolated LA remodeling. However, other studies reported only moderate or weak prediction of AF recurrences using echocardiographic RA diameter. Our study contradicts previous results and shows that RAV ≥ LAV was associated with less LVAs presence, suggesting a rather minor role in LA remodeling. However, we found that males had threefold higher odds for RAV ≥ LAV and less LVAs. Taking into account that females are more prone to LVAs compared to males and have more often-unfavorable outcomes after catheter ablation, our findings are in line with previous research calling for an attention and an urgent need to address underrepresentation of females in clinical research.

### 4.2 Clinical implications

LA diameter (LAD) is an acknowledged marker of advanced electroanatomical remodeling.20,21 LA remodeling is associated with increased atrial volume, interstitial fibrosis, and increased myocardial stretch favoring AF sustainability.22 Previously, we reported that besides anteroposterior LAD, the LAV assessed in CMR is a strong predictor for LVAs presence.6 In current analysis we confirm the role of LA in AF pathogenesis showing that LAV > RAV was associated with sixfold risk for LVAs presence. Although LAV alone showed better predictive value than LAV > RAV (AUC 0.724 vs. 0.668), the difference between ROC curves was not significant. However, the risk of LVAs presence was more obvious using LAV/RAV ratio than LAV alone (OR 5.98 vs. 1.03). Our results indicate that the LA enlargement indexed for the RAV (as self-reference for enlargement) as reflected with the LAV/RAV ratio is a helpful tool for LVAs prediction and for shaping an individualized AF management approach prior to AF catheter ablation.

The present findings add to our knowledge about the importance of side-specific atrial remodeling. As previously described, LA remodeling is associated with later stages of AF progression resulting from risk factors like aging, hypertension, left ventricular (LV) diastolic dysfunction and an altered electromechanical activation.23–26 LV stiffness results into higher LA pressure with reduced LA emptying and consequent atrial dilatation.23 Described pathologic changes represent a
common pathway associated with interatrial delay seen as biphasic P-wave in ECG and caused by deterioration of the Bachmann bundle conduction, and finally impaired electromechanical LA activation.25 These pathophysiologic changes contribute to advanced remodeling and wall deformation that has been associated with LVA.27 Our study supplement these findings of side specific pathophysiological LA changes (especially in relation to RAV) and emphasize the need for accurate pre-procedural LA assessment.

In contrast, pathophysiology of RA remodeling seems to be different. In patients without heart failure, volume and pressure overload in the RA is mainly associated with pulmonary resistance, valvular disease, and RV dysfunction.28–30 Although AF may contribute to RA dilatation as well,31 AF triggers from the RA are rare32 and RA ablation in AF patients has not shown any benefit for outcomes.33 In our study, RAV > LAV was higher in males and was not associated with LVAs. An explanation for such sex-specific difference remains unknown, but it is in accordance with large echocardiographic studies and has not been assigned any clinical significance.34–36

4.3 | Future directions

Our findings show a strong association between LVAs and LAV/RAV ratio. Despite previous data reporting a correlation between RAV ≥ LAV and AF recurrences, our results imply that increased RAV is not a suitable parameter for LVAs prediction and therefore not a marker for left atrial myopathy. This is in line with our previous studies that emphasized the importance of LV diastolic dysfunction, electro-anatomical dysfunction for asymmetric LA remodeling, and ablation outcomes.23–25 Future studies should thus focus on the LA size and its proportional enlargement in relation to the RA, when assessing patients prior to an AF ablation procedure.

4.4 | Limitations

Several limitations could impact interpretation of our results. First, the study is relatively small and included only 33% women. Therefore, statistical analysis for females is very likely underpowered. Similarly, we cannot exclude that male sex is a possible effect modifier analyzing an impact of sex for RAV ≥ LAV. Of note, the study included only patients of European ancestry from a localized area in Eastern Germany, limiting transferability of the results to other ethnic populations. Furthermore, although LVAs are one of parameters describing atrial myopathy, other parameters such as extrapulmonary substrate and triggers or typical atrial flutter, impairing AF ablation outcome, were not assessed. We did not consider arrhythmia recurrences as an outcome after AF catheter ablation due to several issues: (1) In our opinion LVAs are more robust outcome than arrhythmia recurrences, which occur within weeks/months after catheter ablation, while LVAs are measurable during the procedure; (2) Arrhythmia recurrences depend on many factors such as ablator experience, follow-up strategy including antiarrhythmic drug prescription, follow-up frequency, ECG monitoring; (3) In our study, patients did not have a continuous rhythm monitoring. Finally, specific LA fibrosis assessment using late gadolinium enhancement was not conducted in current study and should be addressed in future studies.
5 | CONCLUSIONS

LAV/RAV ratio is useful parameter predicting electro-anatomical substrate in AF. LAV > RAV was associated with sixfold risk for LVAs presence, while male sex was associated with RAV ≥ LAV and less LVAs.

ACKNOWLEDGMENT

Open access funding enabled and organized by Projekt DEAL.

CONFLICT OF INTEREST

Philipp Sommer is in the advisory board for Abbott, Biosense Webster, Medtronic, und Boston Scientific.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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REFERENCES

1. Hunter RJ, McCready J, Diab I, et al. Maintenance of sinus rhythm with an ablation strategy in patients with atrial fibrillation is associated with a lower risk of stroke and death. Heart. 2012;98:48-53.
2. Rolf S, Kircher S, Arya A, et al. Tailored atrial substrate modification based on low-voltage areas in catheter ablation of atrial fibrillation. Circ Arrhythm Electrophysiol. 2014;7:825-833.
3. Gramlich M, Maleck C, Marquardt J, et al. Cryoballoon ablation for persistent atrial fibrillation in patients without left atrial fibrosis. J Cardiovasc Electrophysiol. 2019;30:999-1004.
4. Gupta DK, Shah AM, Giugliano RP, et al. Left atrial structure and function in atrial fibrillation: ENGAGE AF-TIMI 48. Eur Heart J. 2014;35:1457-1465.
5. Seewöster T, Spampinato RA, Sommer P, et al. Left atrial size and total atrial emptying fraction in atrial fibrillation progression. Heart Rhythm. 2019;16:1605-1610.
6. Seewöster T, Büttner P, Nedios S, et al. Association between cardiovascular magnetic resonance-derived left atrial dimensions, Electro-anatomical substrate and NT-proANP levels in atrial fibrillation. J Am Heart Assoc. 2018;7:e009427.
7. Mittal S, Pokushalov E, Romanov A, et al. Long-term ECG monitoring using an implantable loop recorder for the detection of atrial fibrillation after cavitricuspid isthmus ablation in patients with atrial flutter. Heart Rhythm. 2013;10:1598-1604.
8. Chinitz JS, Gerstenfeld EP, Marchlinski FE, Callans DJ. Atrial fibrillation is common after ablation of isolated atrial flutter during long-term follow-up. Heart Rhythm. 2007;4:1029-1033.
9. Sallach JA, Tang WHW, Borowski AG, et al. Right atrial volume index in chronic systolic heart failure and prognosis. JACC Cardiovasc Imaging. 2009;2:527-534.
10. Mantziari L, Kamperidis V, Ventoulis I, et al. Increased right atrial volume index predicts low Duke activity status index in patients with chronic heart failure. Heart J Cardiol-Heart Kardiol Epithe. 2013;54:32-38.
11. Cuttica MJ, Shah SJ, Rosenberg SR, et al. Right heart structural changes are independently associated with exercise capacity in non-severe COPD. PLoS One. 2011;6:e29069.
12. Tang A, Eng JJ, Krassioukov AV, et al. Exercise-induced changes in cardiovascular function after stroke: a randomized controlled trial. Int J Stroke. 2014;9:883-889.
13. Luong C, Thompson DJS, Bennett M, et al. Right atrial volume is superior to left atrial volume for prediction of atrial fibrillation recurrence after direct current cardioversion. Can J Cardiol. 2015;31:29-35.
14. Sasaki T, Nakamura K, Naito S, et al. The right to left atrial volume ratio predicts outcomes after circumferential pulmonary vein isolation of longstanding persistent atrial fibrillation. Pacing Clin Electrophysiol. 2016;39:1181-1190.
15. Hindricks G, Potpara T, Dagres N, et al. 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. 2021;42:373-498.
16. DeLong ER, DeLong DM, Clarke-Pearson DL. Comparing the areas under two or more correlated receiver operating characteristic curves: a nonparametric approach. Biometrics. 1988;44:837-845.
17. Kong Q, Shi L, Yu R, et al. Biatrial enlargement as a predictor for reablation of atrial fibrillation. Int J Med Sci. 2020;17:3031-3038.
18. Wen S-N, Liu N, Bai R, et al. Right atrial diameter and outcome of catheter ablation of atrial fibrillation. J Interv Card Electrophysiol. 2017;49:157-164.
19. Kornej J, Büttner P, Sommer P, et al. Prediction of electro-anatomical substrate using APPLE score and biomarkers. Europace. 2018;21:54-59.
20. Huang D, Li J-B, Zghaib T, et al. The extent of left atrial low-voltage areas included in pulmonary vein isolation is associated with freedom from recurrent atrial arrhythmia. Can J Cardiol. 2018;34:73-79.
21. Montefusco A, Biasco L, Blandino A, et al. Left atrial volume at MRI is the main determinant of outcome after pulmonary vein isolation plus linear lesion ablation for paroxysmal-persistent atrial fibrillation. J Cardiovasc Med. 2010;11:593-598.
22. Inciardi RM, Rossi A. Left atrium: a forgotten biomarker and a potential target in cardiovascular medicine. J Cardiovasc Med. 2019;20:797-808.
23. Nedios S, Koutalas E, Sommer P, et al. Asymmetrical left atrial remodelling in atrial fibrillation: relation with diastolic dysfunction and long-term ablation outcomes. Europace. 2017;19:1463-1469.
24. Nedios S, Koutalas E, Kosiluk J, et al. Impact of asymmetrical dilatation of the left atrium on the long-term success after catheter ablation of atrial fibrillation. Int J Cardiol. 2015;184:315-317.
25. Nedios S, Löbe S, Knopp H, et al. Left atrial activation and asymmetric anatomical remodelling in patients with atrial fibrillation: the relation between anatomy and function. Clin Cardiol. 2020;2021(44):116-122.
26. Nedios S, Tang M, Roser M, et al. Characteristic changes of volume and three-dimensional structure of the left atrium in different forms of atrial fibrillation: predictive value after ablation treatment. J Interv Card Electrophysiol. 2011;32:87-94.
27. Nedios S, Sanaktahni S, Oladosu M, et al. Association of low-voltage areas with the regional wall deformation and the left atrial shape in patients with atrial fibrillation: a proof of concept study. UC Heart Vasc. 2021;33:100730.
28. Topilsky Y. Tricuspid valve regurgitation: epidemiology and pathophysiology. Minerva Cardioangiol. 2018;66:673-679.
29. Alenezi F, Mandawat A, Il’Giove ZJ, et al. Clinical utility and prognostic value of right atrial function in pulmonary hypertension. Circ Cardiovasc Imaging. 2018;11:e006984.
30. Tadic M, Cuspidi C, Suzic-Lazic J, et al. Is there a relationship between right-ventricular and right atrial mechanics and functional capacity in hypertensive patients? J Hypertens. 2014;32:929-937.
31. Ortiz-Leon XA, Posada-Martinez EL, Trejo-Paredes MC, et al. Understanding tricuspid valve remodelling in atrial fibrillation using three-dimensional echocardiography. *Eur Heart J Cardiovasc Imaging*. 2020;21:747-755.

32. Kim K-H, Mohanty S, Mohanty P, et al. Prevalence of right atrial non-pulmonary vein triggers in atrial fibrillation patients treated with thyroid hormone replacement therapy. *J Interv Card Electrophysiol*. 2017;49:111-117.

33. Zarse M, Deharo J-C, Mast F, Allessie MA. Importance of right and left atrial dilation and linear ablation for perpetuation of sustained atrial fibrillation. *J Cardiovasc Electrophysiol*. 2002;13:164-171.

34. Kou S, Caballero L, Dulgheru R, et al. Echocardiographic reference ranges for normal cardiac chamber size: results from the NORRE study. *Eur Heart J Cardiovasc Imaging*. 2014;15:680-690.

35. Soulat-Dufour L, Addetia K, Miyoshi T, et al. Normal values of right atrial size and function according to age, sex, and ethnicity: results of the world Alliance societies of echocardiography study. *J Am Soc Echocardiogr*. 2020;34:286-300.

36. Aune E, Baekkevar M, Roislien J, Rodevand O, Otterstad JE. Normal reference ranges for left and right atrial volume indexes and ejection fractions obtained with real-time three-dimensional echocardiography. *Eur J Echocardiogr*. 2009;10:738-744.

How to cite this article: Seewöster T, Dinov B, Nedios S, Hindricks G, Sommer P, Kornej J. Biattrial volume ratio predicts low voltage areas in atrial fibrillation. *Clin Cardiol*. 2021;44(11):1560-1566. doi:10.1002/clc.23720