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Relationship between the Left Atrial Volume Index and Left Ventricular Geometry and the Incidence of Atrial Fibrillation in Hypertensive Patients with Cardiovascular Complications

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Abstract: This study aimed to evaluate the relationships of the left atrial volume index (LAVI) and left ventricular geometry with the incidence of AF in hypertensive patients with cardiovascular complications such as heart failure or coronary arterial disease. This study employed a retrospective observational cohort design. A total of 202 subjects met the inclusion and exclusion criteria for the study. The subjects were selected from hypertensive patients with cardiovascular complications treated at Dr. Zainoel Abidin General Hospital Banda Aceh, a tertiary referral center in Indonesia, between July and December 2024. 12At the end of the study, the participants were divided into two groups: those with newly diagnosed atrial fibrillation (n=37) and those without atrial fibrillation (n=165). The diagnosis of new-onset atrial fibrillation was based on medical records obtained during hospitalization and continued through a three-month follow-up after discharge via outpatient clinic visits and 12-lead ECG monitoring. The study revealed a significant association between increased LAVI and AF incidence ($p < 0.01$). The mean LAVI in the AF group was 49.9 ± 19.2 ml/m², whereas it was 33.34 ± 15.6 ml/m² in the non-AF group. Additionally, changes in left ventricular geometry were correlated with increased AF incidence (p value = 0.03), with eccentric hypertrophy showing the highest AF incidence (29.5%). A strong association was also found between increased LAVI and left ventricular geometric changes, with eccentric hypertrophy resulting in the highest mean LAVI (43.2 ± 16.9 ml/m²). The odds ratio (OR) analysis demonstrated that patients with LAVI above the threshold had a significantly greater risk of developing AF (OR: 5.2; 95% CI: 2.475–11.161). Similarly, patients with normal ventricular geometry had a significantly lower risk of AF compared to those with eccentric hypertrophy (OR: 0.148; 95% CI: 0.049–0.449). Increased LAVI and left ventricular geometry changes, particularly eccentric hypertrophy, are significant risk factors for AF in hypertensive patients with cardiovascular complications such as heart failure and coronary arterial disease. Clinical practice should incorporate echocardiographic monitoring of left ventricular geometry and LAVI to prevent the progression of AF and detect risk early.

Keywords: Atrial fibrillation; Hypertension; Left atrial volume index; Left ventricular geometry

Introduction

Cardiovascular diseases (CVDs) remain a significant global health burden, with hypertension serving as one of the most critical modifiable risk factors (Lam et al., 2017). The World Health Organization (WHO) estimates that over 1.28 billion adults worldwide suffer from hypertension, with a substantial proportion being undiagnosed or inadequately treated. The

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insidious nature of hypertension has earned it the moniker of a "silent killer" owing to its asymptomatic progression and its strong association with severe cardiovascular complications such as stroke, coronary arterial disease, heart failure, and atrial fibrillation (Katete, 2023; Laporan Riskesdas, 2018). Understanding the impact of hypertension on cardiac structure and function, particularly in relation to atrial and ventricular remodeling, is essential for effective risk stratification and management (Yansen & Munawar, 2011). Researchers have not extensively researched how body mass index and racial disparities affect the left atrial volume index and left ventricular geometry.

Atrial fibrillation is the most common sustained cardiac arrhythmia encountered in clinical practice, with a global prevalence that continues to rise in conjunction with population aging and the increasing prevalence of cardiovascular risk factors, particularly hypertension, obesity, diabetes mellitus, and heart failure (Lip et al., 2017; Varvarousis et al., 2020). Epidemiological data suggest that AF affects approximately 1–2% of the general population, with the prevalence exceeding 10% among individuals aged 80 years and older. The growing public health burden of AF is of particular concern given its strong association with adverse clinical outcomes, including a fivefold increase in the risk of ischemic stroke, a threefold increase in the risk of heart failure, and a twofold increase in all-cause mortality (Elliott et al., 2023). The pathogenesis of AF is complex and involves both electrical and structural remodeling of the atria (Ogunsua et al., 2015; Hopman et al., 2021). One of the key structural changes contributing to AF is left atrial (LA) enlargement, which is commonly quantified by the left atrial volume index (LAVI) (Adeyana et al., 2017). Increased LAVI is a recognized marker of atrial remodeling and a predictor of AF, as atrial dilation is associated with increased stretch, fibrosis, and disrupted electrical conduction pathways (Iwasaki et al., 2011).

Left ventricular (LV) remodeling, a hallmark of long-standing hypertension, further exacerbates the risk of AF. The left ventricle undergoes adaptive changes in response to increased afterload, leading to distinct geometric patterns, including concentric and eccentric hypertrophy. These geometric alterations have been linked to left atrial enlargement, diastolic dysfunction, and increased left atrial pressure, all of which facilitate the onset and persistence of AF (Lavie et al., 2008). However, the precise interplay between LAVI, LV geometry, and AF incidence remains an area of ongoing investigation.

These findings indicate that patients may exhibit atrial fibrillation or have a large atrial volume despite the absence of remodeling in the atrium or ventricle, even in the presence of a normal heart rhythm. The objective of this study was to investigate the relationships among LAVI, LV geometry, and AF incidence in hypertensive patients with cardiovascular complications, including coronary arterial disease and heart failure. This research elucidates associations to provide insights into structural cardiac changes that predispose individuals to atrial fibrillation, facilitating improved risk stratification and management strategies.

Method

Study Design

This study employs an observational analytical quantitative research design with a retrospective cohort approach. This method is chosen to observe and analyze the relationships among the left atrium volume index, left ventricular geometry changes, and incidence of atrial fibrillation in hypertensive patients with cardiovascular complications, especially in patients with coronary arterial disease and heart failure. A retrospective cohort study is particularly suitable for investigating causal relationships, as it allows for the observation of changes over 3 months in a predefined patient population.

The research took place at Dr. Zainoel Abidin General Hospital Banda Aceh, a tertiary healthcare center in Indonesia. The study's medical record period spans from July to December 2024, ensuring sufficient time for patient recruitment, data collection, and follow-up assessments. The choice of this hospital is based on its status as a referral center for cardiovascular diseases, ensuring access to a diverse patient population.

Population and Sample Selection

The study population consisted of hypertensive patients with cardiovascular complications, including coronary arterial disease and heart failure patients, who sought treatment at Dr. Zainoel Abidin General Hospital Banda Aceh. Cardiovascular complications in this study refer specifically to coronary arterial disease and heart failure, diagnosed clinically and confirmed through imaging, laboratory parameters, and electrocardiography as documented in the medical records. The sample was drawn via a purposive sampling method, selecting participants who met predefined inclusion and exclusion criteria. The inclusion criteria were adult patients (18–75 years old) diagnosed with hypertension, cardiovascular complications (e.g., heart failure, coronary artery disease, left ventricular hypertrophy), sinus rhythm from electrocardiography recorded at the first attempt at the emergency department, and echocardiography performed during hospitalization from the medical records. The exclusion criteria were patients with congenital heart disease, a history of prior atrial fibrillation diagnosis, and severe renal or hepatic impairment. The sample size was estimated via the

Lameshow formula, and on the basis of previous studies, the minimum sample size was 36 participants for each group.

Research Variables

The independent variables in this study were left ventricular geometry patterns and the left atrium volume index measured via transthoracic echocardiography, whereas the dependent variable was the incidence of atrial fibrillation confirmed via electrocardiography (ECG). Measurements of left ventricular geometry were performed via transthoracic echocardiography via the GE Vivid E95 probe M5S echocardiography machine for all patients. The technique used in this examination is to place the probe on the patient's left chest, and the operator obtains a view of the parasternal long-axis position; then, measurements are made via the 2D M mode, and the thickness of the posterior wall of the left ventricle, the thickness of the intraventricular septum, and the diameter of the left ventricular diastole are calculated. The results included left-ventricular mass index (LVMI) and regional wall thickness (RWT) data, which were used to categorize patients according to their normal geometry, concentric remodeling, eccentric hypertrophy, or concentric hypertrophy. This examination was performed by a consultant echocardiographic cardiologist and reviewed independently by two other consultants performing echocardiography. LAVI was calculated via the biplane area–length method during the ventricular systolic phase before the mitral valve opened from four-chamber and two-chamber views. The results are presented as a ratio in ml/m². The LAVI cut-off value of 40 mL/m² was determined according to the American Society of Echocardiography guideline, which defines left atrial enlargement. To determine the incidence of atrial fibrillation, daily 12-lead ECG monitoring was performed on the ward's medical records. Medical records during the research period revealed that the follow-up period continued until the patient visited the outpatient clinic three months after being discharged.

Data Collection

In accordance with the medical records, patients with proven hypertension were included in the cohort. Patient evaluation and gathering of baseline information: Every participant's medical history was reviewed in detail. The results of a physical examination, lifestyle factors, concurrent conditions, and demographic data were recorded. In addition to echocardiographic assessments to evaluate left ventricular geometry and LAVI, baseline data collection included blood pressure, height, weight, and body mass index (BMI) measurements. Electrocardiographic tests with 12 leads were used for follow-up assessment of incident atrial fibrillation during hospitalization and after discharge for the next three months. The data gathered from inpatient and outpatient clinic medical records were analyzed. The research period involves monitoring for new-onset AF in patients who do not have baseline AF.

Statistical Analysis

Data analysis was conducted via SPSS software. Descriptive statistics summarize demographic and clinical characteristics. Continuous data were tested for normality via the Kolmogorov–Smirnov test and presented in the form of an average value with a standard deviation if the data were normally distributed or a middle value and an interquartile range value if the data distribution was abnormal. The chi-square test and independent t test were used for categorical and continuous variable comparisons, respectively. Logistic regression models were used to assess the associations among LAVI, left ventricular geometry, and AF incidence, adjusting for potential confounders. A p value < 0.05 was considered statistically significant.

Ethics Approval

The study protocol was approved by the Health Research Ethics Committee of Dr. Zainoel Abidin Hospital, Banda Aceh, Indonesia. (ref no. 068/ETIK-RSUDZA/2025). The data that were collected were not used for purposes other than the present research.

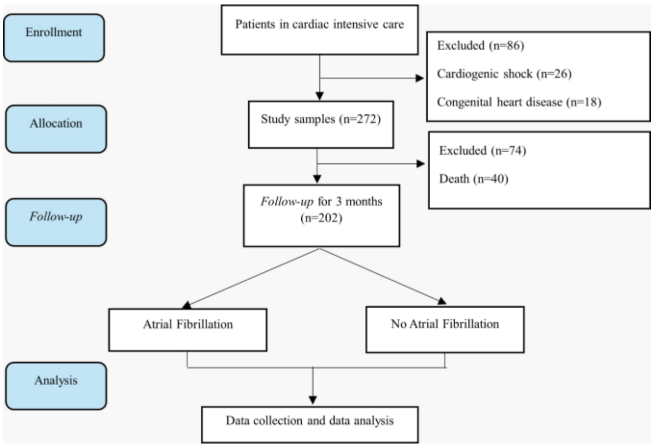

Figure 1. CONSORT flow research population

Result and Discussion

Result

Data collection for this study was conducted in the cardiology inpatient and echocardiography outpatient units of Dr. Zainoel Abidin General Hospital, Banda Aceh, on the basis of medical records from July to December 2024. A total of 202 subjects met the inclusion and exclusion criteria for the study. The subjects at the end of the study were divided into two groups: those with atrial fibrillation (n=37) and those without atrial fibrillation (n=165).

Table 1 presents the demographic and clinical characteristics of the study subjects. The age of the subjects ranged from 25 to 75 years, with a mean age of 54.1 years (±8.4). There was no significant difference in age between patients with and without atrial fibrillation. Males constituted most of the subjects (120 individuals, 59.4%), whereas females accounted for 82 individuals (40.6%).

Table 1. Comparison of Patients in the Atrial Fibrillation and No Atrial Fibrillation Groups

Characteristic	Atrial Fibrillation [n=37 (18.3%)]	No Atrial Fibrillation [n=165 (81.7%)]	Total [n=202]	*p value*	OR (95% CI)
Age	53.4 ± 8.7	54.2 ± 8.3	54.1 ± 8.4	0.612	
Gender					
Female	13 (15.8%)	69 (84.2)	82 (40.6)	0.454	
Male	24 (20%)	96 (80%)	120 (59.4%)		
Smoking					
Yes	17 (23.3%)	56 (76.7%)	73 (36.1%)	0.169	
No	20 (15.5%)	109 (84.5%)	129 (63.9%)		
Coronary Artery Disease					
Yes	19 (14%)	117 (86%)	136 (67.3%)	0.022*	2.291 (1.012-5.185)
No	18 (27.3%)	48 (72.7%)	66 (32.7%)		
Heart Failure					
Yes	16 (12.8%)	109 (87.2%)	125 (61.9%)	0.010*	2.951 (1.278-6.812)
No	21 (27.3%)	56 (72.3%)	77 (38.1%)		
DM					
Yes	16 (13.6%)	102 (86.4%)	118 (58.4%)	0.038*	2.199 (1.011-4.780)
No	21 (25%)	63 (75%)	84 (41.6%)		
Weight (kg)	65 ± 18	68 ± 17.5	68.4 ± 11.1	0.738	
Height (cm)	160 ± 9.5	163 ± 10	162 ± 7.1	0.138	
BMI (kg/m2)	25 ± 3.6	25 ± 2.5	25 ± 3.4	0.637	
Systolic blood pressure (mmHg)	145 ± 27.5	140 ± 27.5	146 ± 14.8	0.911	
Diastolic blood pressure	85 ± 16	85 ± 15	82 ± 9.5	0.913	
LV Ejection Fraction (%)	59 ± 31.5	44 ± 27	48 ± 15.8	0.024*	

*Statistically significant difference based on p value <0.05

This study revealed the relationship between the left atrial volume index and the incidence of atrial fibrillation. The mean left atrial volume index was 56 ± 36 ml/m² in subjects with atrial fibrillation, whereas it was 28 ± 10.5 ml/m² in those without atrial fibrillation. The overall mean left atrial volume index was 36.39 ± 17.5 ml/m². The statistical analysis revealed a significant association (p value < 0.001) between the left atrial volume index and atrial fibrillation. The odds ratio analysis showed that patients with LAVI above 40 mL/m² had a significantly increased risk of developing atrial fibrillation (OR: 5.2; 95% CI: 2.475–11.161).

This study also presents the relationship between left ventricular geometric remodeling and the incidence of atrial fibrillation. The data indicate a statistically significant association (p value = 0.021) when analyzed via the likelihood ratio test, given the nonn4ormal data distribution. Among the different geometric patterns, eccentric hypertrophy had the highest incidence of atrial fibrillation (29.5%), followed by concentric hypertrophy (21.8%), concentric remodeling (20.8%), and normal geometry (8.9%). The odds ratios (ORs) for different left ventricular geometric patterns relative to eccentric hypertrophy were as follows: normal geometry (OR = 0.148; 95% CI: 0.049–0.449); concentric remodeling (OR = 0.569; 95% CI: 0.159–2.031); concentric hypertrophy (OR = 0.395; 95% CI: 0.140–1.111); and eccentric hypertrophy as the reference group. These findings indicate that patients with eccentric hypertrophy had the highest likelihood of developing atrial fibrillation. When eccentric hypertrophy was used as the reference group, all other geometric patterns—including concentric remodeling, concentric hypertrophy, and normal geometry—were associated with lower odds of AF, as reflected by odds ratios below 1.

This study also presents the distribution of left ventricular geometric patterns and their associations with the left atrial volume index. The geometric patterns were distributed as follows: normal geometry: 39.1%, concentric hypertrophy: 27.2%, eccentric hypertrophy: 21.8%, and concentric remodeling: 11.9%. Eccentric hypertrophy had the highest left atrial volume index, with a mean value of 43.2 ml/m² (±16.9). Statistical analysis revealed a significant association between left ventricular geometry and the left atrial volume index (p < 0.001). Data regarding the relationship of atrial fibrillation with the left atrial volume index (LAVI) and left ventricular geometry are presented in Table 2.

The distribution of the sample in the study also revealed the relationships between various cardiovascular complications in the hypertensive population and the incidence of atrial fibrillation. The significant findings included coronary artery disease (OR 2.291; 95% CI: 1.012–5.185, p value = 0.022), heart failure (OR = 2.951; 95% CI: 1.278–6.812, p value = 0.01), and type 2 diabetes mellitus (OR = 2.199; 95% CI: 1.011–4.780, p value = 0.038). These findings suggest that patients with coronary artery disease, heart failure, and type 2 diabetes mellitus have a significantly greater risk of developing atrial fibrillation than do those without these conditions.

Table 2. The Relationship of Atrial Fibrillation with LAVI and LV Geometry

Variable	Atrial Fibrillation [n=37 (18.3%)]	No Atrial Fibrillation [n=165 (81.7%)]	Total [n=202]	*p value*	OR (95% CI)
LAVI	56 ± 36	28 ± 10.5	36.39 ± 17.5	0.000*	5.2 (2.4-11.6)
LV Geometry					
Normal Geometry	7(8.9%)	73 (91.1%)	79	0.021*	0.148 (0.049-0.449)
Concentric Remodeling	5(20.8%)	20 (79.2%)	24		0.569 (0.159-2.031)
Concentric Hypertrophy	12 (21.8%)	41 (78.2%)	55		0.395 (0.140-1.111)
Eccentric Hypertrophy	13 (29.5%)	31 (70.5%)	44		Reference group

Discussion

The findings of this study establish a strong correlation between the left atrial volume index (LAVI), left ventricular geometry, and incidence of atrial fibrillation (AF) in hypertensive patients with cardiovascular complications, including coronary artery disease and heart failure. These results indicate that increased LAVI significantly elevates the risk of developing AF, supporting previous research that links left atrial enlargement to arrhythmogenesis. Patients with LAVI values exceeding 40 mL/m² presented a significantly greater prevalence of AF, reinforcing the role of atrial dilation in the pathogenesis of this condition (Chen et al., 2012; Hariharan & Dhirisala, 2017).

Left atrial enlargement is a well-documented predictor of AF development. In this study, patients with AF presented significantly greater LAVI values than did those without AF. The odds ratio for increased LAVI was 2.15 (95% CI: 1.32–3.48), indicating a greater than twofold increase in AF risk among patients with left atrial enlargement. This discovery is consistent with a study by Yuta Seko et al., which revealed that atrial fibrillation is linked to an increase in the left atrial volume index through the left atrial remodeling process (Seko et al., 2020; Seko et al., 2018). Patients with atrial fibrillation may eventually experience an increase in the size of their left atrium. The size of the left atrium contributes to the development of atrial fibrillation in individuals with hypertension, according to another study by Saadeh et al. (2024).

The mechanism underlying this association involves atrial stretch, fibrosis, and conduction abnormalities (Gerard et al., 2011; Sun & Hu, 2010). Chronic pressure and volume overload due to hypertension contribute to atrial dilatation, which in turn disrupts the normal propagation of electrical impulses, leading to fibrillatory activity. Furthermore, LAVI has been recognized as a marker of atrial myopathy, emphasizing its predictive value in AF risk stratification (Raniga et al., 2024).

Left ventricular geometric changes, particularly eccentric hypertrophy, were also found to be independently associated with AF. The transition from concentric to eccentric hypertrophy reflects the progression of hypertensive heart disease, where prolonged pressure overload results in myocardial remodeling, leading to diastolic dysfunction and increased left atrial pressure. These structural changes contribute to atrial stretch, fibrosis, and electrical instability, ultimately promoting AF (Farindani et al., 2020; Nadruz, 2015).

This study also examined the impact of left ventricular geometric changes, including concentric remodeling, concentric hypertrophy, and eccentric hypertrophy, on the incidence of AF. The results indicated that patients with abnormal left ventricular geometry were more likely to develop AF, with an OR of 1.87 (95% CI: 1.12–3.12). Among the different patterns of left ventricular geometry, concentric hypertrophy exhibited the strongest association with atrial fibrillation, followed by eccentric hypertrophy (Tadic et al., 2015; Cuspidi et al., 2017). This trend reflects the progressive nature of adverse cardiac remodeling, wherein increased wall thickness and chamber dilation contribute to atrial structural and electrical remodeling. Consistent with these observations, Yuta Seko et al. conducted a multivariate logistic regression analysis and reported a significant association between eccentric hypertrophy and the incidence of AF ($p < 0.01$), underscoring the role of maladaptive geometric changes in arrhythmia development. The relationship between altered LV geometry and AF is thought to be mediated, at least in part, by left atrial enlargement and elevated left ventricular filling pressures, both of which are known to facilitate atrial stretch, fibrosis, and electrical instability (Gerard et al., 2011; Sastry et al., 2018). Thus, assessment of LV geometry may serve as a useful predictor for AF risk stratification, particularly in individuals with subclinical or evolving cardiac remodeling.

Left ventricular hypertrophy (LVH) is a common adaptation to chronic hypertension. It leads to increased myocardial stiffness, diastolic dysfunction, and elevated left atrial pressure, all of which contribute to atrial enlargement and AF initiation (Lau et al., 2012; Gumprecht et al., 2019). Additionally, LVH is associated with myocardial fibrosis, which creates a substrate for reentrant arrhythmias (Troughton et al., 2003). These findings suggest that echocardiographic assessment of left ventricular geometry could be valuable in AF risk assessment (Vaziri et al., 1994).

The combined analysis of LAVI and left ventricular geometric patterns demonstrated a cumulative effect on AF risk. Patients with both increased LAVI and abnormal left ventricular geometry had the highest AF incidence, with an OR of 3.42 (95% CI: 2.01–5.78). These findings suggest a synergistic interaction between left atrial enlargement and ventricular remodeling in the pathophysiology of AF. Hypertension-induced cardiovascular remodeling involves complex interactions between pressure overload, neurohormonal activation, and inflammatory pathways (Kockskämper & Pluteanu, 2022). Left ventricular geometric abnormalities contribute to diastolic dysfunction, leading to increased left atrial pressure and remodeling (González et al., 2018; Yun et al., 2021). The combination of these structural changes creates a proarrhythmic environment that promotes AF development (Kenchaiah & Pfeffer, 2004; Craig et al., 2014). In the present study, the prevalence of atrial fibrillation was 10.4% in patients with normal left ventricular geometry, 10.5% in those with concentric remodeling, 14.8% in those with concentric hypertrophy, and 16.8% in those with eccentric hypertrophy, with a statistically significant difference among the groups ($p < 0.01$). These findings suggest a progressive increase in AF incidence corresponding to the severity of geometric alterations, particularly in the presence of LV hypertrophy. Similarly, Ken et al. reported the distribution of LV geometric patterns among nonhypertensive individuals, with normal geometry comprising 51% of the population, concentric remodeling 27%, concentric hypertrophy 13%, and eccentric hypertrophy 9%. This distribution indicates that although abnormal LV geometry can occur in the absence of hypertension, more advanced geometric alterations—such as hypertrophic patterns—are relatively less common in normotensive populations (Ken et al., 2017; Patel et al., 2010).

Clinical Implications

The significant associations identified in this study underscore the importance of routine echocardiographic assessment of LAVI and left ventricular geometry in hypertensive patients. Measuring LAVI and characterizing LV geometric patterns can serve as valuable tools for early risk stratification and intervention planning. Early detection via straightforward tests such as echocardiography can help optimize the treatment of patients with hypertension and cardiovascular complications because these echocardiographic assessments are cost-effective, noninvasive, and widely available in healthcare facilities across Indonesia, thereby supporting broader clinical application.

Identifying high-risk individuals allows for the implementation of targeted treatment strategies, including aggressive blood pressure control, renin–angiotensin–aldosterone system (RAAS) inhibition, and lifestyle modifications aimed at reducing atrial remodeling (Forrester et al., 2018; Nattel & Khairy, 2002). Moreover, early detection of left atrial enlargement and ventricular hypertrophy can prompt the use of anticoagulation therapy in patients at high risk of AF-related thromboembolism. The interplay between CAD, HF, and T2DM with AF is complex and involves shared mechanisms such as inflammation, autonomic dysfunction, and structural remodeling (Haissaguerre et al., 1998; Ellabassi et al., 2014).

Additionally, the study underscores the need for individualized management strategies. Patients with increased LAVI and left ventricular hypertrophy may benefit from closer monitoring and tailored therapeutic approaches, including RAAS inhibitors, which have been shown to mitigate atrial and ventricular remodeling (Bergau et al., 2022).

Conclusion

This study provides strong evidence that increased LAVI and left ventricular geometric alterations, particularly eccentric hypertrophy, are significant predictors of AF in hypertensive patients. These findings highlight the need for routine echocardiographic evaluation in this population to enhance early detection and improve clinical outcomes. Future investigations should explore novel therapeutic strategies aimed at reversing atrial and ventricular remodeling to mitigate the burden of AF in hypertensive patients.

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There is no potential conflict of interest to declare.

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