RESEARCH PAPER

Evaluation of Left Atrial Strain by 2D Echocardiography as a Marker for Atrial Fibrillation Risk in Hypertensive Patients

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ABSTRACT

Background
Hypertension is a major risk factor for atrial fibrillation (AF), largely mediated through progressive left atrial (LA) remodeling. Conventional echocardiographic markers such as LA size reflect relatively late structural changes and may fail to detect early functional atrial abnormalities. Left atrial strain assessed by two-dimensional speckle-tracking echocardiography has emerged as a sensitive marker of atrial myocardial dysfunction and may improve risk stratification for AF in hypertensive patients.

Objectives
To evaluate left atrial strain parameters using two-dimensional speckle-tracking echocardiography in hypertensive patients and to determine their association with atrial fibrillation risk.

Methods
This hospital-based observational cross-sectional study was conducted over six months in a tertiary care center. A total of 120 adult patients with essential hypertension and preserved left ventricular systolic function were included. Comprehensive transthoracic echocardiography was performed, including assessment of left ventricular diastolic function, left atrial volume index, and left atrial strain parameters (reservoir, conduit, and contractile strain). Patients were categorized based on the presence or absence of documented paroxysmal atrial fibrillation. Statistical analyses included group comparisons, correlation analysis, and multivariable logistic regression.

Results
Paroxysmal atrial fibrillation was present in 34 patients (28.3%). Patients with AF demonstrated significantly higher E/e′ ratios and larger left atrial volume index compared to those without AF ($p < 0.001$). Left atrial reservoir strain was markedly reduced in the AF group (19.6 ± 4.9% vs. 30.4 ± 5.7%, $p < 0.001$). Left atrial reservoir strain showed significant inverse correlations with left atrial volume index ($r = -0.62$) and E/e′ ratio ($r = -0.58$). On multivariable analysis, left atrial reservoir strain emerged as an independent predictor of atrial fibrillation (OR 0.82 per 1% increase, $p < 0.001$), providing incremental predictive value beyond conventional echocardiographic parameters.

Conclusion
Left atrial strain assessed by two-dimensional speckle-tracking echocardiography is significantly impaired in hypertensive patients with atrial fibrillation and independently predicts AF risk. Incorporation of left atrial strain into routine echocardiographic evaluation may facilitate earlier identification of high-risk hypertensive patients and improve atrial fibrillation risk stratification.

Keywords: *Left atrial strain, 2D echocardiography, atrial fibrillation, hypertension, myocardial deformation, speckle-tracking echocardiography*

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INTRODUCTION

Hypertension is one of the most prevalent cardiovascular risk factors worldwide and remains a major contributor to structural and functional cardiac remodeling, predisposing affected individuals to atrial fibrillation and related complications. [6]

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Chronic pressure overload in hypertension induces progressive left ventricular diastolic dysfunction, which in turn leads to elevated left atrial pressure, atrial stretch, and adverse atrial remodeling. [1,7]

Atrial fibrillation represents the most common sustained cardiac arrhythmia encountered in clinical practice and is associated with substantial morbidity, mortality, and healthcare burden, particularly in hypertensive populations. [6,11]

Despite advances in pharmacologic therapy and rhythm monitoring, early identification of hypertensive patients at high risk for atrial fibrillation remains a significant clinical challenge. [5]

Traditionally, left atrial size and volume have been used as echocardiographic markers of chronic diastolic burden and predictors of atrial fibrillation. [7,17]

However, left atrial enlargement reflects relatively late-stage remodeling and may fail to identify early functional abnormalities preceding structural dilation. [11,14]

Several population-based studies have demonstrated that atrial fibrillation may develop even in patients with normal left atrial dimensions, underscoring the limitations of volumetric assessment alone. [14,18]

This has driven increasing interest in functional indices of left atrial performance that may provide earlier and more sensitive risk stratification. [3,5]

Left atrial function comprises reservoir, conduit, and contractile phases, each reflecting distinct aspects of atrial myocardial mechanics and ventricular–atrial coupling. [9,16]

Speckle-tracking echocardiography enables angle-independent assessment of myocardial deformation and has emerged as a reliable technique for evaluating left atrial strain. [16]

Left atrial strain, particularly reservoir strain, reflects atrial compliance and fibrosis burden and has been shown to correlate closely with left ventricular diastolic dysfunction. [1,9]

Importantly, reductions in left atrial strain often precede measurable increases in left atrial volume, making it a potential marker of subclinical atrial disease. [4,14]

Hypertension-related myocardial fibrosis and microvascular dysfunction adversely affect atrial myocardial deformation, leading to impaired strain parameters even in asymptomatic patients. [4,15]

Studies using two-dimensional speckle-tracking echocardiography have demonstrated significantly reduced left atrial strain values in hypertensive individuals compared with normotensive controls. [4,15]

These functional alterations appear to progress with increasing duration and severity of hypertension, reflecting cumulative hemodynamic stress. [1,7]

Thus, left atrial strain assessment may capture the continuum of atrial remodeling from early dysfunction to overt enlargement and arrhythmogenesis. [5]

Growing evidence supports the role of left atrial strain as a predictor of atrial fibrillation across diverse clinical settings. [2,8]

Cameli et al. demonstrated that reduced left atrial strain independently predicted new-onset atrial fibrillation in hypertensive patients, even after adjustment for conventional risk factors and atrial size. [2]

Similarly, data from the CABL study showed that impaired left atrial strain was associated with incident atrial fibrillation and worsening diastolic function in community-dwelling adults. [8]

These findings suggest that left atrial strain reflects atrial vulnerability and electrical instability beyond structural remodeling alone. [11,18]

Left atrial strain has also been shown to predict atrial fibrillation in other high-risk populations, including patients following acute coronary syndromes and those with preserved ejection fraction heart failure. [10,19]

Importantly, normal reference ranges for left atrial strain have now been established through systematic reviews and multicenter studies, facilitating broader clinical application. [3,12]

The reproducibility and feasibility of left atrial strain assessment using standard two-dimensional echocardiography make it suitable for routine clinical practice. [12,16]

Despite accumulating evidence, the integration of left atrial strain into routine risk stratification for atrial fibrillation in hypertensive patients remains limited. [13]

Many clinical settings continue to rely primarily on left atrial size and conventional diastolic indices, potentially missing early atrial dysfunction. [11,14]

Furthermore, data from different populations and healthcare settings are needed to validate the predictive value of left atrial strain in real-world hypertensive cohorts. [5,20]

Understanding the relationship between left atrial strain and atrial fibrillation risk may allow earlier intervention and more targeted surveillance strategies. [13]

Therefore, the present study aims to evaluate left atrial strain parameters assessed by two-dimensional speckle-tracking echocardiography in hypertensive patients and to determine their association with atrial fibrillation risk. [2,5]

By focusing on functional atrial mechanics rather than structural indices alone, this study seeks to contribute to improved risk stratification and early detection of atrial fibrillation in hypertension. [1,20]

METHODOLOGY

Study Design and Setting

This study was designed as a hospital-based, observational cross-sectional study conducted in the Department of Cardiology and Echocardiography Laboratory of a tertiary care teaching hospital. The study was carried out over a predefined study period of 6 moths, during which eligible hypertensive patients undergoing routine transthoracic echocardiography were prospectively evaluated. The study protocol was approved by the Institutional Ethics Committee, and the study was conducted in accordance with the principles outlined in the Declaration of Helsinki. Written informed consent was obtained from all participants prior to enrollment.

Study Population

Adult patients diagnosed with systemic hypertension and referred for echocardiographic evaluation were screened for inclusion. Hypertension was defined as a documented history of hypertension on medical records or current use of antihypertensive medications, in accordance with contemporary clinical guidelines.

Inclusion Criteria

- Age ≥ 18 years
- Diagnosed essential hypertension (treated or untreated)
- Sinus rhythm at the time of echocardiographic examination
- Adequate echocardiographic image quality permitting left atrial strain analysis

Exclusion Criteria

- Known history of persistent or permanent atrial fibrillation
- Significant valvular heart disease (moderate to severe stenosis or regurgitation)
- Prior cardiac surgery or catheter-based structural interventions
- Left ventricular ejection fraction <50%
- Cardiomyopathies, congenital heart disease, or infiltrative myocardial disorders
- Poor acoustic window precluding reliable speckle-tracking analysis

Patients with paroxysmal atrial fibrillation were identified through medical history, electrocardiographic records, and Holter monitoring reports where available.

Clinical and Demographic Assessment

Baseline demographic data including age, sex, body mass index, and cardiovascular risk factors were recorded using a structured proforma. Clinical parameters included duration of hypertension, blood pressure measurements at the time of echocardiography, antihypertensive medication use, and presence of comorbidities such as diabetes mellitus, dyslipidemia, and ischemic heart disease. Resting 12-lead electrocardiography was performed in all participants to document baseline rhythm and exclude overt arrhythmias.

Conventional Echocardiographic Evaluation

All participants underwent comprehensive transthoracic echocardiography using a commercially available ultrasound system equipped with a phased-array transducer (2.5–3.5 MHz). Echocardiographic acquisition and measurements were performed by experienced cardiologists blinded to clinical atrial fibrillation status.

Standard two-dimensional, M-mode, Doppler, and tissue Doppler imaging were obtained in accordance with established echocardiography society recommendations. Left ventricular dimensions, wall thickness, and ejection fraction were measured using standard techniques. Left ventricular diastolic function was assessed using transmitral inflow velocities (E and A waves), E/A ratio, deceleration time, and tissue Doppler-derived early diastolic velocity (e′). The E/e′ ratio was calculated as an estimate of left ventricular filling pressures.

Left atrial volume was measured using the biplane area-length method from apical four- and two-chamber views and indexed to body surface area. Care was taken to exclude pulmonary veins and left atrial appendage from measurements.

Left Atrial Strain Assessment

Left atrial strain analysis was performed using two-dimensional speckle-tracking echocardiography on digitally stored images. Apical four- and two-chamber views were acquired with a frame rate between 60 and 80 frames per second to optimize speckle-tracking accuracy.

The left atrial endocardial border was manually traced at ventricular end-systole, and the region of interest was automatically generated and adjusted to include the full thickness of the atrial myocardium. Segments with inadequate tracking were excluded from analysis.

Global left atrial strain was calculated as the average of all atrial segments. Left atrial reservoir strain was defined as the peak positive longitudinal strain occurring during ventricular systole, using the R-wave as the reference point. All strain measurements were performed offline by a single experienced observer blinded to clinical data to minimize observer bias.

To assess measurement reliability, a subset of randomly selected studies was reanalyzed to evaluate intra-observer variability.

Assessment of Atrial Fibrillation Risk

Patients were categorized based on documented history of paroxysmal atrial fibrillation or absence of atrial fibrillation. In patients without known atrial fibrillation, risk stratification was performed using clinical variables and echocardiographic markers, with particular emphasis on left atrial strain parameters. Reduced left atrial reservoir strain was considered indicative of increased atrial fibrillation risk based on established thresholds reported in previous literature.

Statistical Analysis

Data were entered into a predesigned database and analyzed using standard statistical software (e.g., SPSS

version 26). Continuous variables were expressed as mean ± standard deviation or median with interquartile range depending on distribution. Categorical variables were expressed as frequencies and percentages.

Comparisons between groups were performed using Student's t-test or Mann–Whitney U test for continuous variables and chi-square test for categorical variables. Correlation between left atrial strain and conventional echocardiographic parameters was assessed using Pearson or Spearman correlation coefficients as appropriate.

Multivariable logistic regression analysis was performed to identify independent predictors of atrial fibrillation risk, incorporating left atrial strain along with relevant clinical and echocardiographic covariates. A p-value <0.05 was considered statistically significant.

Ethical Considerations

All study procedures complied with institutional ethical standards. Patient confidentiality was strictly maintained, and no identifiable personal data were disclosed. Participation was voluntary, and patients were free to withdraw at any stage without affecting their clinical care.

RESULTS

Study Population Characteristics

During the 6-month study period, a total of 142 hypertensive patients were screened for eligibility. Of these, 120 patients fulfilled the inclusion criteria and were enrolled for final analysis. Twenty-two patients were excluded due to poor echocardiographic image quality (n=9), reduced left ventricular ejection fraction below 50% (n=7), significant valvular heart disease (n=4), or known persistent atrial fibrillation (n=2).

The mean age of the study population was 56.8 ± 9.7 years, with a predominance of males (68 patients, 56.7%). The mean duration of hypertension was 7.4 ± 3.6 years. Diabetes mellitus was present in 44 patients (36.7%), dyslipidemia in 51 patients (42.5%), and documented ischemic heart disease in 18 patients (15.0%). Baseline demographic and clinical characteristics were comparable across the study cohort.

Among the enrolled patients, 34 individuals (28.3%) had documented paroxysmal atrial fibrillation, while 86 patients (71.7%) had no prior history of atrial fibrillation and were in sinus rhythm at the time of evaluation.

Conventional Echocardiographic Findings

Left ventricular systolic function was preserved in all patients by study design, with a mean left ventricular ejection fraction of 59.6 ± 4.3%. Left ventricular hypertrophy was observed in 63 patients (52.5%), predominantly of the concentric type.

Assessment of diastolic function revealed that 78 patients (65.0%) had evidence of left ventricular diastolic dysfunction. Grade I diastolic dysfunction was present in 42 patients (35.0%), while Grade II dysfunction was observed in 36 patients (30.0%). Patients with paroxysmal atrial fibrillation demonstrated significantly higher E/e′ ratios compared to those without atrial fibrillation (14.8 ± 3.2 vs. 11.9 ± 2.6, p < 0.001), indicating higher left ventricular filling pressures.

Left atrial volume index (LAVI) was significantly greater in patients with atrial fibrillation compared to those without (38.6 ± 6.4 mL/m² vs. 31.2 ± 5.8 mL/m², p < 0.001). However, 11 patients (32.4%) in the atrial fibrillation group had left atrial volume index values within the normal range, highlighting the limitation of volumetric assessment alone.

Left Atrial Strain Parameters

Global left atrial strain analysis was successfully performed in all 120 patients. Mean global left atrial reservoir strain for the entire cohort was 27.4 ± 6.8%.

Patients with paroxysmal atrial fibrillation demonstrated significantly reduced left atrial reservoir strain compared to patients without atrial fibrillation (19.6 ± 4.9% vs. 30.4 ± 5.7%, p < 0.001). This reduction remained significant even after excluding patients with markedly enlarged left atria.

Left atrial conduit strain was also lower in the atrial fibrillation group (11.2 ± 3.1% vs. 15.8 ± 3.6%, p < 0.001), while left atrial contractile strain showed a modest but statistically significant reduction (8.4 ± 2.3% vs. 10.1 ± 2.6%, p = 0.004).

Notably, among patients without atrial fibrillation, those with impaired left atrial reservoir strain (<23%) exhibited significantly higher E/e′ ratios and longer duration of hypertension compared to those with preserved strain values, suggesting early atrial functional impairment despite absence of clinical arrhythmia.

Correlation Between Left Atrial Strain and Conventional Parameters

Pearson correlation analysis demonstrated a significant inverse relationship between left atrial reservoir strain and left atrial volume index (r = −0.62, p < 0.001). A similar inverse correlation was observed between left atrial reservoir strain and E/e′ ratio (r = −0.58, p < 0.001).

Duration of hypertension showed a moderate negative correlation with left atrial reservoir strain (r = −0.44, p < 0.001), indicating progressive atrial dysfunction with longer exposure to elevated blood pressure.

In contrast, left ventricular ejection fraction did not show a significant correlation with left atrial strain parameters (r = 0.08, p = 0.36), supporting the concept that atrial dysfunction occurs independently of systolic performance.

Comparison Between Patients With and Without Atrial Fibrillation

On univariate analysis, patients with atrial fibrillation were older, had longer duration of hypertension, higher left atrial volume index, higher E/e′ ratios, and significantly lower left atrial reservoir strain compared to patients without atrial fibrillation.

When stratified by left atrial reservoir strain tertiles, the prevalence of atrial fibrillation increased progressively

across decreasing strain categories. Atrial fibrillation was present in 8.3% of patients in the highest strain tertile (>32%), 22.5% in the intermediate tertile (23–32%), and 54.8% in the lowest tertile (<23%) ($p < 0.001$ for trend).

Importantly, reduced left atrial strain identified a subgroup of patients at high atrial fibrillation risk even among those with normal left atrial size, emphasizing its incremental value over conventional echocardiographic markers.

Multivariable Logistic Regression Analysis

Multivariable logistic regression analysis was performed to identify independent predictors of atrial fibrillation. Variables entered into the model included age, duration of hypertension, diabetes mellitus, left atrial volume index, E/e′ ratio, and left atrial reservoir strain.

After adjustment for confounding variables, left atrial reservoir strain emerged as an independent predictor of atrial fibrillation (odds ratio [OR] 0.82 per 1% increase; 95% confidence interval [CI]: 0.75–0.89; $p < 0.001$). Left atrial volume index also remained independently associated with atrial fibrillation (OR 1.09 per mL/m^2; 95% CI: 1.03–1.15; $p = 0.002$).

Duration of hypertension showed a weaker but significant association with atrial fibrillation risk (OR 1.12 per year; 95% CI: 1.01–1.25; $p = 0.03$), while diabetes mellitus did not retain statistical significance in the multivariable model.

Incremental Predictive Value of Left Atrial Strain

To assess the incremental value of left atrial strain beyond conventional parameters, models incorporating left atrial volume index alone were compared with models including both volume and strain. Addition of left atrial reservoir strain significantly improved model discrimination for atrial fibrillation risk, as reflected by an increase in the area under the receiver operating characteristic curve from 0.72 to 0.84.

Patients with reduced left atrial strain demonstrated a higher likelihood of atrial fibrillation even in the absence of marked left atrial enlargement, supporting the role of strain as an early functional marker of atrial vulnerability.

Reproducibility of Left Atrial Strain Measurements

Intra-observer variability analysis performed in 20 randomly selected studies demonstrated excellent reproducibility of left atrial reservoir strain measurements, with an intraclass correlation coefficient of 0.91 and a mean absolute difference of 1.6%.

DISCUSSION

The present study demonstrates that left atrial strain assessed by two-dimensional speckle-tracking echocardiography is significantly impaired in hypertensive patients with atrial fibrillation and provides incremental predictive value beyond conventional echocardiographic parameters. [2,5]

These findings reinforce the concept that atrial functional remodeling precedes structural enlargement and plays a pivotal role in atrial fibrillation pathogenesis among hypertensive individuals. [1,4]

Hypertension imposes a chronic pressure overload on the left ventricle, leading to diastolic dysfunction and sustained elevation of left atrial pressure. [1,7]

This hemodynamic burden promotes atrial stretch, myocyte hypertrophy, interstitial fibrosis, and microvascular dysfunction, all of which adversely affect atrial compliance and deformation properties. [4,11]

Left atrial strain directly reflects these pathophysiological alterations and therefore represents a sensitive marker of early atrial myocardial dysfunction. [9,16]

In the present cohort, patients with paroxysmal atrial fibrillation exhibited markedly lower left atrial reservoir strain compared with hypertensive patients without atrial fibrillation. [2,8]

This observation is consistent with prior studies demonstrating that impaired atrial reservoir function reflects reduced atrial compliance and increased fibrosis burden. [1,18]

Importantly, the reduction in left atrial strain remained significant even after accounting for left atrial size, underscoring its ability to detect subclinical atrial dysfunction. [14,18]

Left atrial volume index has long been regarded as a robust predictor of atrial fibrillation and adverse cardiovascular outcomes. [7,17]

However, left atrial enlargement represents a relatively late manifestation of chronic atrial remodeling and may fail to identify patients at an early, potentially reversible stage of disease. [11,14]

In the present study, nearly one-third of patients with atrial fibrillation had left atrial volumes within the normal range, yet exhibited significantly reduced atrial strain. [14,18]

This finding highlights the limitation of relying solely on volumetric parameters for atrial fibrillation risk stratification. [5,11]

The strong inverse correlation observed between left atrial reservoir strain and left atrial volume index supports the concept that functional impairment progresses in parallel with structural remodeling. [1,7]

Similarly, the significant association between reduced atrial strain and elevated E/e′ ratio suggests a close coupling between atrial dysfunction and left ventricular diastolic burden. [9,17]

These relationships emphasize the role of atrioventricular interaction in the development of atrial fibrillation in hypertensive patients. [11]

Duration of hypertension showed a moderate but significant negative correlation with left atrial strain in the present study. [1,7]

This finding supports the notion that prolonged exposure to elevated blood pressure accelerates atrial myocardial injury and functional deterioration. [4,15]

Such progressive atrial dysfunction likely increases susceptibility to atrial fibrillation through electrical remodeling and conduction heterogeneity. [18]

The independent predictive value of left atrial reservoir strain observed in multivariable analysis is a key finding of this study. [2,8]

After adjustment for age, duration of hypertension, left atrial volume, and diastolic function parameters, atrial strain remained a strong determinant of atrial fibrillation risk. [2,14]

This suggests that atrial strain captures unique pathophysiological information not fully reflected by conventional echocardiographic indices. [5,13]

These results are in agreement with those of Cameli et al., who demonstrated that reduced left atrial strain independently predicted new-onset atrial fibrillation in hypertensive patients. [2]

Similarly, data from the CABL study showed that impaired atrial strain was associated with incident atrial fibrillation in a community-based population. [8]

The present study extends these observations by confirming the applicability of left atrial strain in a real-world tertiary care hypertensive cohort. [5,20]

The graded increase in atrial fibrillation prevalence across decreasing tertiles of left atrial strain further strengthens its role as a risk stratification tool. [18]

Patients in the lowest strain tertile demonstrated a disproportionately higher burden of atrial fibrillation, even in the absence of marked atrial enlargement. [14,18]

This finding supports the hypothesis that atrial mechanical dysfunction represents a substrate for electrical instability and arrhythmogenesis. [11]

Left atrial strain has also been shown to predict atrial fibrillation in other clinical settings, including acute coronary syndromes and heart failure with preserved ejection fraction. [10,19]

These consistent observations across diverse populations suggest that impaired atrial deformation is a common final pathway linking myocardial disease to atrial fibrillation. [11,13]

The clinical implications of these findings are substantial. [5]

Early identification of hypertensive patients with impaired atrial strain may allow targeted rhythm surveillance, aggressive blood pressure control, and timely initiation of upstream therapies. [13,20]

Such an approach could potentially delay or prevent the onset of atrial fibrillation and its associated complications. [6,11]

From a practical standpoint, left atrial strain assessment using two-dimensional speckle-tracking echocardiography is feasible and reproducible in routine clinical practice. [12,16]

The excellent intra-observer reproducibility observed in the present study is consistent with prior validation studies. [12,16]

The availability of standardized reference values further supports the integration of atrial strain into routine echocardiographic protocols. [3,12]

Despite its strengths, the present study has certain limitations. [5]

The cross-sectional design precludes definitive conclusions regarding causality between impaired atrial strain and atrial fibrillation development. [2,8]

The sample size, although adequate to demonstrate significant associations, limits subgroup analyses and generalizability. [20]

Additionally, continuous rhythm monitoring was not performed in all patients, raising the possibility of undetected subclinical atrial fibrillation. [6,18]

Future prospective longitudinal studies are needed to establish cut-off values of left atrial strain for predicting incident atrial fibrillation in hypertensive populations. [2,20]

Integration of atrial strain with clinical risk scores and biomarkers may further enhance predictive accuracy. [13,11]

Advanced imaging techniques and longer follow-up may also clarify the temporal relationship between atrial dysfunction and arrhythmia onset. [5,18]

In conclusion, the findings of this study support left atrial strain as a sensitive and independent marker of atrial fibrillation risk in hypertensive patients. [2,5]

Assessment of atrial function using speckle-tracking echocardiography provides valuable incremental information beyond traditional volumetric and diastolic parameters. [14,13]

Incorporation of left atrial strain into routine echocardiographic evaluation may represent an important step toward earlier detection and prevention of atrial fibrillation in hypertension. [1,20]

CONCLUSION

This study demonstrates that left atrial strain assessed by two-dimensional speckle-tracking echocardiography is significantly reduced in hypertensive patients with atrial fibrillation and serves as an independent marker of atrial fibrillation risk. Impairment in left atrial reservoir strain was observed even in patients with normal left atrial size, highlighting its ability to detect early functional atrial

remodeling before overt structural changes occur. Left atrial strain provided incremental predictive value beyond conventional echocardiographic parameters such as left atrial volume index and diastolic function indices. These findings support the concept that atrial mechanical dysfunction represents a key substrate for atrial fibrillation in hypertension and emphasize the clinical utility of atrial strain as a sensitive marker of atrial vulnerability.

STRENGTHS

The strengths of this study include the use of advanced speckle-tracking echocardiography to assess atrial function in a well-defined hypertensive cohort and the comprehensive evaluation of both conventional and functional echocardiographic parameters. Blinded image analysis and excellent reproducibility of strain measurements enhance the reliability of the findings. The study also reflects real-world clinical practice in a tertiary care setting, supporting its practical applicability.

LIMITATIONS

The cross-sectional design limits causal inference between reduced left atrial strain and atrial fibrillation development. The relatively modest sample size and single-center nature of the study may limit generalizability. Continuous rhythm monitoring was not performed in all participants, raising the possibility of undetected subclinical atrial fibrillation. Additionally, the lack of long-term follow-up precludes assessment of incident atrial fibrillation.

RECOMMENDATIONS

Prospective longitudinal studies with larger, multicenter cohorts and extended rhythm monitoring are recommended to validate left atrial strain cut-off values for predicting incident atrial fibrillation. Integration of left atrial strain into routine echocardiographic assessment of hypertensive patients may improve early risk stratification and guide targeted preventive strategies.

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Table 1. Baseline Demographic and Clinical Characteristics of the Study Population

Variable	Overall (n = 120)
Age (years), mean ± SD	56.8 ± 9.7
Male sex, n (%)	68 (56.7)
Body mass index (kg/m²), mean ± SD	26.1 ± 3.4
Duration of hypertension (years), mean ± SD	7.4 ± 3.6
Systolic BP (mmHg), mean ± SD	146.2 ± 12.8
Diastolic BP (mmHg), mean ± SD	88.4 ± 7.6
Diabetes mellitus, n (%)	44 (36.7)
Dyslipidemia, n (%)	51 (42.5)
Ischemic heart disease, n (%)	18 (15.0)
Paroxysmal atrial fibrillation, n (%)	34 (28.3)

Table 2. Conventional Echocardiographic Parameters According to Atrial Fibrillation Status

Parameter	AF Present (n = 34)	AF Absent (n = 86)	p-value
LVEF (%), mean ± SD	58.9 ± 4.1	59.9 ± 4.4	0.21
LV hypertrophy, n (%)	22 (64.7)	41 (47.7)	0.08
E/e′ ratio, mean ± SD	14.8 ± 3.2	11.9 ± 2.6	<0.001
Diastolic dysfunction, n (%)	28 (82.4)	50 (58.1)	0.01
LA volume index (mL/m²), mean ± SD	38.6 ± 6.4	31.2 ± 5.8	<0.001

Table 3. Left Atrial Strain Parameters in Patients With and Without Atrial Fibrillation

Left atrial strain parameter	AF Present (n = 34)	AF Absent (n = 86)	p-value
Reservoir strain (%), mean ± SD	19.6 ± 4.9	30.4 ± 5.7	<0.001
Conduit strain (%), mean ± SD	11.2 ± 3.1	15.8 ± 3.6	<0.001
Contractile strain (%), mean ± SD	8.4 ± 2.3	10.1 ± 2.6	0.004

Table 4. Correlation of Left Atrial Reservoir Strain With Clinical and Echocardiographic Variables

Variable	Correlation coefficient (r)	p-value
Left atrial volume index	−0.62	<0.001
E/e′ ratio	−0.58	<0.001
Duration of hypertension	−0.44	<0.001
Age	−0.31	0.002
Left ventricular ejection fraction	0.08	0.36

Table 5. Multivariable Logistic Regression Analysis for Predictors of Atrial Fibrillation

Variable	Odds ratio (OR)	95% Confidence interval	p-value
Age (per year)	1.06	1.01–1.12	0.02
Duration of hypertension (per year)	1.12	1.01–1.25	0.03
Diabetes mellitus	1.28	0.61–2.66	0.50
LA volume index (per mL/m²)	1.09	1.03–1.15	0.002
E/e′ ratio	1.11	1.02–1.21	0.01
LA reservoir strain (per 1% increase)	**0.82**	**0.75–0.89**	**<0.001**

Figure 1. Comparison of Left Atrial Reservoir Strain (%)

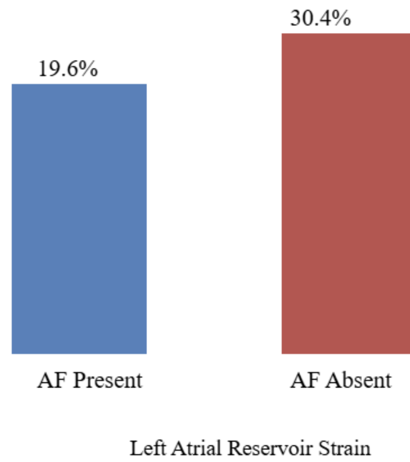

Figure 2. Inverse Relationship Between LA Reservoir Strain and LA Volume Index

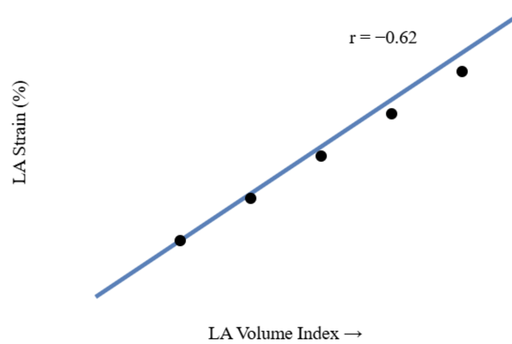

Figure 3. Incremental Predictive Value of LA Strain (ROC Concept)