



## Review Article

# Assessing left atrial function in acute decompensated heart failure: Insights from echocardiography

Nisa Amnifolia Niazta<sup>1\*</sup>, Wella Karolina<sup>2,3</sup>, Anna Fuji Rahimah<sup>2,3</sup>, Indra Prasetya<sup>2,3</sup>

<sup>1</sup> Brawijaya Cardiovascular Research Center, Department of Cardiology and Vascular Medicine, Faculty of Medicine, Universitas Brawijaya, Malang, Indonesia

<sup>2</sup> Department of Cardiology and Vascular Medicine, Faculty of Medicine, Universitas Brawijaya, Malang, Indonesia

<sup>3</sup> Dr. Saiful Anwar General Hospital, Malang, East Java, Indonesia

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## ABSTRACT

Acute heart failure remains a major cause hospitalization, especially in older adults and is associated with mortality and frequent readmissions. Several factors associated with heart failure outcomes include left ventricular dysfunction, left atrial dysfunction, and LA enlargement. LA enlargement has been recognized as a dependable imaging marker, closely tied to adverse outcomes such as heart failure, stroke, atrial fibrillation, and mortality. LA is not merely a passive conduit for transport. LA plays an active role and responds to distension by releasing atrial natriuretic peptides. LA enlargement has been shown to correlate with poor cardiovascular prognosis. In patients experiencing acute heart failure, fluid overload and its reduction can alter LA mechanical performance. Decongestive treatment has been associated with improved LA reservoir function, which can be assessed through parameters like LA reservoir strain rate also peak atrial longitudinal strain. In more advanced heart failure—characterized by reduced left ventricular ejection fraction, increased filling pressures, then diminished cardiac output—both PALS and strain rate are often markedly impaired, reflecting significant dysfunction in LA reservoir. Evaluating left atrial function via echocardiographic techniques is proving to be a vital tool in predicting outcomes for individuals with acute decompensated heart failure. As the understanding of LA physiology evolves, its role is increasingly seen as dynamic rather than passive. Echocardiography is showing potential imaging biomarker for risk stratification and therapeutic guidance in heart failure management.

## 1. Introduction

Acute heart failure is the top reason people over 65 are hospitalized and is strongly tied to high risks of death and being readmitted. Death rates during hospitalization range from 4% to 10%, and up to 30% of patients may die within a year of discharge. When combined with readmissions, the total risk can rise above 45%.<sup>1</sup> The left atrium isn't just a passive channel for blood—it actively responds to stretch by releasing hormones called atrial natriuretic peptides. The balance of natriuresis, vasodilation, and suppression of the sympathetic and renin-angiotensin-aldosterone systems facilitates partial recovery of fluid and hemodynamic balance.<sup>2</sup> LA enlargement is recognized as a detrimental predictor for cardiovascular events.<sup>3-5</sup> The LA volume index is considered a more accurate indicator of cardiovascular risk compare to the LA area or LA diameter in patients with sinus rhythm, but in those with atrial fibrillation, the predictive value of LA size for cardiovascular events is less satisfactory.<sup>6</sup>

In response to various stimuli specifically mechanical, electrical, and metabolic, the LA might undergo structural remodeling, leading to dilation and functional impairment.<sup>7</sup> Enlargement and dysfunction of the LA are recognised as indicators of systolic and diastolic dysfunction, as well as prognosticators of cardiovascular outcomes, including atrial fibrillation, heart failure, stroke, and death. Over the past few decades, the idea of LA remodeling has advanced, and the role of LA to heart failure pathophysiology has been recognized.<sup>8</sup>

Alteration in LA structure and function can be indicators of heart failure severity or mechanisms that dynamically facilitate the progression of heart dysfunction. LA dysfunction is illustrated by atrial fibrillation, which significantly increases morbidity in heart failure patients. Current research shows that appropriate treatment approach can mitigate the detrimental process of LA remodeling and possibly facilitate reversal LA remodeling leading to improvement in symptoms and clinical outcomes.<sup>9</sup> Therefore, preventing LA dysfunction and treating LA disease could become essential.

## 2. Discussion

### Acute Heart Failure

Acute heart failure is the most common cause of hospitalization in individuals aged over 65 years of age and is closely linked to increased mortality and readmission rates. In-hospital mortality rates range from 4% to 10%, while one-year post-hospitalization mortality rate may reach 25-30% with a mortality or readmission rate of more than 45%. Newly diagnosed heart failure patients may have greater in-hospital mortality rates, but they also had lower post-discharge mortality and readmission rates than patients with acute decompensated congestive heart failure.<sup>1</sup> Different Asian nations have different incidence rates for heart failure.

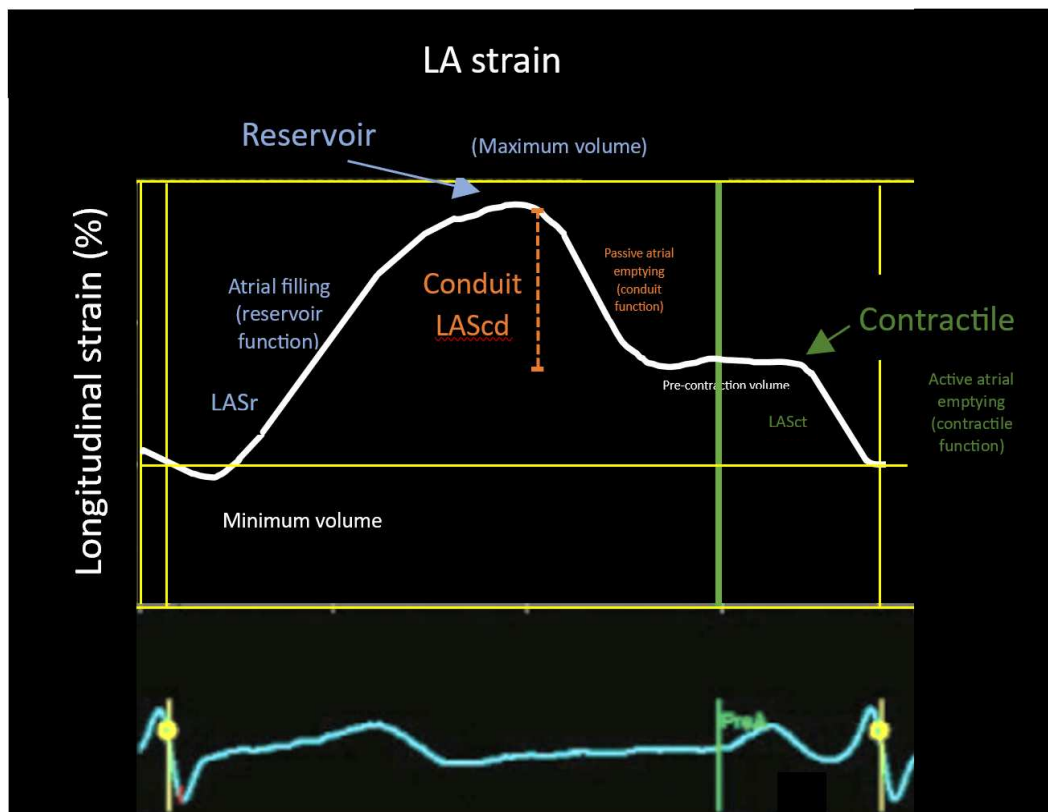
\* Corresponding author at: Brawijaya Cardiovascular Research Center, Department of Cardiology and Vascular Medicine, Faculty of Medicine, Universitas Brawijaya, Malang, Indonesia

E-mail address: [nisaamnifolianiadzta@gmail.com](mailto:nisaamnifolianiadzta@gmail.com) (N.A. Niazta).

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**Figure 1.** LA function and LA volume during cardiac cycle; LAScd: left atrial strain conduit phase; LASct: left atrial strain contractile phase; LASr: left atrial strain reservoir phase

For example, Hong Kong records a heart failure prevalence of 2-3%, Thailand has a prevalence rate of 0.4%, Philippines records 1-2%, South Korea reports 0.6%, Taiwan recorded 6%, Malaysia 6.7%, and Singapore 4.5%. In 2018, the Indonesian Basic Health Research (Risikesdas) presented data that the prevalence of heart disease, including acute heart failure, reaching approximately 1.5% in the population aged over 15 years.<sup>10-12</sup> Previous study conducted by Kamila et al (2021) showed 18% patient hospitalized with acute decompensated heart failure were experience 90 days mortality.<sup>13</sup>

According to the universal definition and classification, heart failure is defined as a clinical syndrome characterised by signs and symptoms resulting from abnormalities structure and/or cardiac function and followed by an increase in natriuretic peptide and/or objective evidence of pulmonary or systemic congestion.<sup>14</sup> Heart failure is not a distinct pathological diagnosis but a clinical syndrome characterized by cardinal symptoms including shortness of breath, leg edema, and fatigue, which may be accompanied by objective signs such as increased jugular venous pressure, rhonchi in the lungs, and peripheral edema). This condition happens when changes in the structural and/or functional abnormalities of the heart rise intracardiac pressure and/or inadequate cardiac output, either at rest or during physical activity. The term "Acute heart failure" describe sudden or progressive onset of signs and symptoms of heart failure that are severe enough to typically require hospitalization or unplanned visits to the emergency department. There are two types of acute heart failure presentations acute heart, namely acute heart failure that has just occurred for the first time (de novo) and heart failure decompensated heart failure in previously stable chronic heart failure.<sup>1</sup> Patients with acute heart failure require immediate prompt assessment and initiation or escalation of subsequent treatment, include intravenous therapy or interventions.

Individuals with acute heart failure face a high risk of mortality not only from cardiovascular failure but also from organ dysfunction caused by congestion and hypoperfusion, so treatment strategies must address both issues. Despite randomized controlled trials provide less evidence that alleviating congestion enhances survival diuretics have shown clear benefits in reducing symptoms and organ congestion. Once oxygen levels are stabilized—through

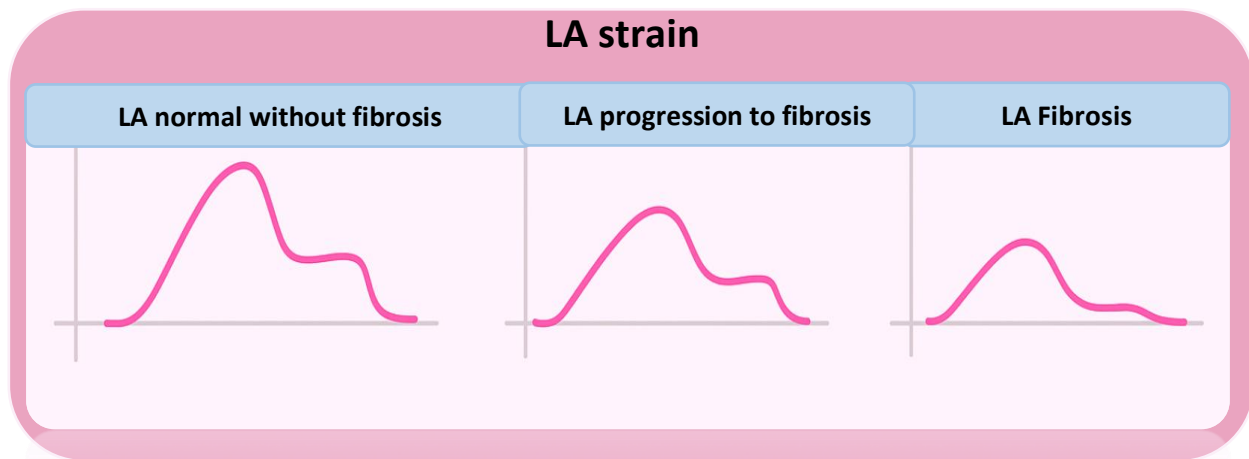
supplemental oxygen, non-invasive support, or mechanical ventilation—the main therapeutic goals are to eliminate fluid overload without leaving residual congestion, optimize perfusion pressure to support organ function, and continue or adjust oral medications that modulate neurohormonal activity to enhance diuretic effectiveness and improve long-term outcomes.<sup>15</sup>

#### Atrial Function

Research on the left atrium has steadily grown. In the early 1980s, many studies focused on defining normal size ranges. Over the past decade, left atrial size has proven to be a dependable imaging marker, closely linked to key outcomes such as heart failure, atrial fibrillation, stroke, and death. Recently, the functional assessment of LA has proven to be an external marker of cardiovascular health. Current research indicates that combining measurements of left atrial size and function leads to more accurate predictions of cardiovascular outcomes.<sup>1</sup> The left atrium does more than passively move blood—it actively responds to stretching by releasing atrial natriuretic peptides. The balance of natriuresis, vasodilation, and suppression of the sympathetic and renin-angiotensin-aldosterone systems facilitates partial recovery of fluid and hemodynamic balance.<sup>2</sup> An enlarged LA has been proven to be a detrimental predictor of cardiovascular complications.<sup>3-5</sup> For individuals with sinus rhythm, measuring the LA's volume index gives a clearer picture of cardiovascular risk than just checking its area or diameter. But in those with atrial fibrillation, this measurement isn't as effective at predicting future cardiovascular events.<sup>6</sup>

#### Phasic left atrial function

The three phases of the cardiac cycle provide a straightforward explanation of the mechanical function of the LA.<sup>16</sup> The LA first functions as a "reservoir" that collects blood from the pulmonary venous return and holds onto energy in the form of pressure during ventricular systole and isovolumetric relaxation. After the mitral valve opens through a pressure gradient, blood passively flows from the pulmonary veins to the left ventricle through LV diastasis, and the LA then serves as a "channel or conduit" for the passage of blood to the left ventricle (LV) during the early stages of



**Figure 1.** The stages of left atrial function are demonstrated by longitudinal studies and LA strain and myocardial fibrosis in the atrium.

ventricular diastole. The LA's "contractile" function usually results in a 20% rise in the LV stroke volume. In the treatment of LV dysfunction, the role of this "booster pump" function becomes increasingly important.<sup>17</sup> The size of the left atrium changes throughout the cardiac cycle. In most clinical settings, only its largest size is measured. However, its function during different phases of the cycle can be better understood by looking at several volume points, not just the maximum<sup>5</sup>:

- 1) Peak left atrial (LA) volume occurs just before the mitral valve opens.
- 2) Minimum LA volume is seen when the mitral valve closes.
- 3) LA reservoir volume—the total amount the LA empties—is calculated by subtracting the minimum volume from the maximum.
- 4) Passive emptying volume is the difference between the maximum LA volume and the volume right before atrial contraction (marked by the P wave on ECG).
- 5) Active emptying volume reflects atrial contraction and is found by subtracting the minimum LA volume from the pre-contraction volume.
- 6) The conduit volume, or passive flow from LA to LV, is estimated by subtracting the total LA emptying volume from the left ventricular stroke volume.

#### Physiological factors affecting left atrial function

Elastic properties and downstream pressure play major role in determining the left atrial afterload, and the left atrial afterload rises with the severity of LV diastolic dysfunction and the increase in LV filling pressure.<sup>18</sup> On the other hand, LA preload primarily depends on volume. Research on humans and animals has shown that the size of the left atrium (LA) increases with the rise in volume and pressure in the LA, with the initial increase associated with contractile shortening. Progressive LA dilation leads to fiber length threshold, atrial shortening, and contractility begins to decrease. The effect of this threshold or tipping point seems to be similar to the Frank-Starling curve of the left ventricle. Beyond that point, further stretching will cause atrial function decrease.<sup>19</sup> The relationship between the LV and LA has interactive and dynamic characteristics.<sup>5,20</sup> Regional blood flow, blood pressure, cardiac output, and heart rate control are all impacted by neurohumoral regulation. The cardiovascular system suffers when this system is activated over an extended period of time. For example, changes in the LA's structure can be worsened by increases in brain and atrial natriuretic peptide, aldosterone, angiotensin II, and other neurohormonal variables.<sup>21</sup> In particular, when the angiotensin-aldosterone system stays active for too long, it triggers inflammation, profibrotic with decreased atrial contractility, proarrhythmic, and prothrombotic.<sup>2</sup>

#### Methods of left atrial functional assessment

Various methods for evaluating left atrial function include echocardiography, CT, and MRI. Currently, echocardiography currently presents the simplest, non invasive, and least expensive method.

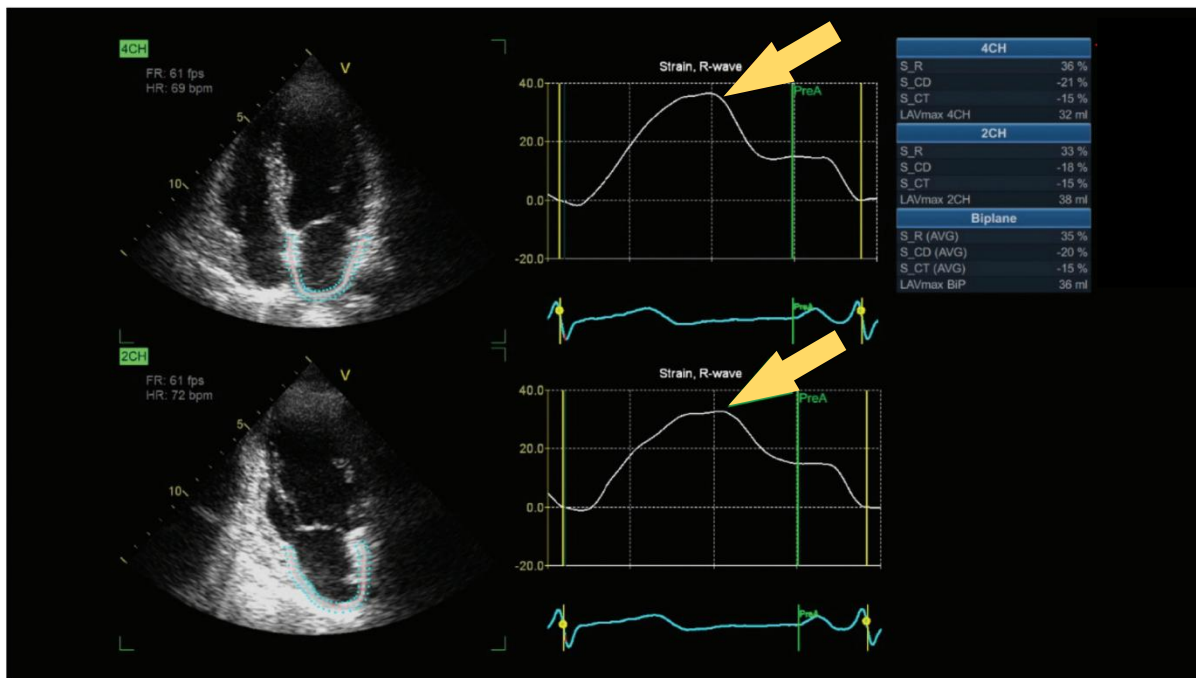
Consequently, slight variations in volume measurements by echocardiography and other imaging techniques are not clinically relevant, what's important is that the results are compared to normal values from the same technique using the same approach. The LA volume is measured at different points in the cardiac cycle in order to use volumetric methods to evaluate the left atrium's phasic function. The largest LA volume is recorded just after the T wave on an ECG, right before the mitral valve opens. The minimum LA volume is noted during the QRS complex, when the mitral valve closes, and the preceding atrial contraction (pre-A) is captured at the P wave. The apical four and two chamber viewpoints are used in the biplanar area length and the biplanar Simpson technique. For individuals with a typical body size, the average LA volume is  $22 \pm 5-6$  mL/m<sup>2</sup>. The smallest volume, seen when the atrium is most empty, is around 11 mL/m<sup>2</sup>. Just before the atrium contracts, the volume is usually close to 15 mL/m<sup>2</sup>.

#### Methods of left atrial functional assessment using doppler echocardiography

Left atrial (LA) function can be evaluated by using pulsed wave Doppler to measure flow at the tip of the mitral valve leaflets during early (E wave) and late (A wave) diastolic filling. The peak velocity of these waves, particularly the E wave, serves as a marker of LA performance. In healthy young individuals, normal E wave velocity is around  $0.8 \pm 0.2$  m/s.<sup>22</sup> Several studies currently use this value as an index for assessing LA function. However, this evaluation is influenced by age and LA strain. Atrial function can be assessed by calculating the ratio of atrial systole to the total mitral inflow using time-velocity integrals (TVI). This is expressed as:  $(TVI \text{ mitral A}) / (TVI \text{ mitral E} + TVI \text{ mitral A})$ . This ratio gives insight into the contribution of atrial contraction to overall ventricular filling. According to the Framingham Heart Study, a higher mitral E/mitral A TVI is linked to a higher risk of AF. The speed of blood briefly flowing backward into the pulmonary vein—called atrial reversal—is another way to assess how the left atrium functions. This small backflow happens when the atrium contracts, often due to stiffer heart walls and higher filling pressure. The most accurate readings are taken from the apical view at the end of a breath out, using a 3–5 mm sample placed 1–2 cm inside the right upper pulmonary vein.<sup>2</sup>

#### Methods of left atrial functional assessment using tissue doppler echocardiography

Tissue Doppler imaging (TDI) helps measure the assessment of intrinsic myocardial wall velocity using a high-speed sampling method. It's less affected by changes in pressure or volume and adds prognostic value in heart disease. Tissue Doppler imaging (TDI) of the mitral annulus typically reveals three main waveforms: the S' wave, representing peak systolic velocity during ventricular contraction; the E' wave, reflecting early diastolic filling; and the A' wave, which occurs during atrial contraction. Numerous research may have demonstrated a very good correlation between the mitral annulus A' and the function of atrial. In patients with varying degrees of LV diastolic dysfunction,



**Figure 2.** Measurement of LA strain with speckle tracking. The yellow arrows indicate the peak reservoir strain in the 4 chamber and 2 chamber echocardiographic views. The right box explained automatic results for the measurement of the reservoir, conduit, and contraction in the 4 chamber, 2 chamber views, and Biplane.

this is strongly correlated with LA ejection fraction, LA ejection force, and LA kinetic energy. Tissue doppler imaging should be acquired toward the end of expiration, with an average of three sinus beats, alongside the sample volume positioned on the atrial side of the mitral annulus at the basal interatrial septum seen from the apical four-chamber perspective. The speed range must be established between 20 to 220 cm/s utilizing minimal gain and decrease filter settings. Similar to other Doppler methods, the angle and the structures around the myocardium have an impact on the tissue Doppler velocity.<sup>2</sup>

#### Methods of left atrial functional assessment using strain echocardiography

Strain or strain rate (SR) echocardiographic imaging provides information on myocardial deformation by measuring the spatial gradient of myocardial velocity. This novel imaging technique has been used in a number of studies to evaluate atrial function (Table 1). Unlike colour TDI, this approach appears to be unaffected by heart movement and the contraction of adjacent segments. Since the atrial wall is thin and only 5 mm above the atrioventricular junction, images are taken using a small sector. High-speed images (200 Hz) of the left atrium's side (lateral) and middle (septal) walls are captured using the four-chamber view. The front (anterior) and back (inferior) walls can also be assessed using the two-chamber view. To avoid errors from angle distortions or signal noise, the atrial wall must be aligned as closely as possible with the Doppler beam. Each frame is then carefully tracked with specialized software to keep the sample point centered in the correct spot. Standard strain rate values for these walls were first documented in 2006.<sup>2</sup>

The surrounding structures and related segments have an impact on the TDI velocity measurement of deformation or strain. An innovative technique for assessing cardiac deformation is two-dimensional speckle tracking imaging (2D-SI). Instead of using Doppler myocardial velocity, this technique uses acoustic speckle tracking, and it does not require precise ultrasound beam alignment. Since it was first introduced in 2004, many studies have highlighted 2D speckle tracking imaging (2D-SI) as a promising tool for evaluating how the left atrium functions. This method tracks small rectangular areas in the heart's image, each with a unique speckle pattern, using standard grayscale ultrasound visuals. Traditionally, when the LA is at its smallest volume, the line is purposefully traced along the LA endocardium. The software will generate the desired area, usually along 15 mm, next to the epicardial and mid-myocardial lines. Manual modifications may also be implemented if required.<sup>23,24</sup>

The left atrial endocardial borders are delineated manually or automatically (excluding pulmonary veins and LAA) on high-resolution two-dimensional pictures captured at a frame rate of 50 to 90 frames per second, three to five cardiac cycles, ensuring similar heart rate for each view. The EACVI/ASE task force advocates for the utilization of the left atrial strain value derived from non-foreshortened apical four- and two-chamber views, however the apical four-chamber strain alone is frequently used and demonstrated to be beneficial. The first approach utilizes the QRS onset from electrocardiography as the reference point (R-R gating) and quantifies two principal left atrial (LA) deformations: the LA reservoir (LASr), which peaks at the end of left ventricular (LV) systole, and LA contraction (LASct), which occurs later and correlates to LA contraction. The difference between LASr and LASct implies LA Conduit (LAScd). The second gating method employs the electrocardiographic P wave as the reference point (P-P gating), facilitating the assessment of two deformations: the initial down-sloping, indicative of LASct, and the subsequent up-sloping, reflecting atrial relaxation and reservoir function.<sup>25,26</sup>

#### Relationship of left ventricular filling pressure and left atrial reservoir strain echocardiography

Left atrial reservoir strain (LASr) demonstrates a direct link with the grade of diastolic dysfunction (LASr reduces as diastolic dysfunction increases) and is inversely associated with Left Ventricular Filling Pressure (LVFP), a decrease in LARS corresponds to an increase in LVFP. As a late diastolic measure, LASct (pump strain) reveals an inverse relationship with LVEDP; a less negative LASct corresponds to a higher LVEDP. LASr contributes additionally to traditional Doppler parameters and left atrial volume index for the noninvasive assessment of left ventricular filling pressure. Evidence shows its strong association with increased filling pressures. In a single-center prospective study including 139 patients, a LASr of less than 23% demonstrated a higher ability to predict invasive left ventricular filling pressures, as assessed by pre-A-wave left ventricular catheterization measurements. A substantial multicenter international investigation by Sade et al. involving 322 patients established that a left atrial strain (LASr) of less than 18% serves as the ideal threshold for identifying high filling pressures, primarily utilizing end-expiratory pulmonary capillary wedge pressure as the reference standard.<sup>38-41</sup>

The latest ASE recommendation in 2025 regarding the evaluation of left ventricular (LV) diastolic function is structured into two phases: the initial assessment of indicators of impaired LV

**Table 1.** Research related to strain and strain rate in the function of LA<sup>2</sup>

Author	Population	Research findings related to the function of LA were measured based on the strain technique.
<b>Research on strain and strain rate with Doppler</b>		
Wang <i>et al</i> <sup>27</sup>	Hypertensive patients with atrial tachycardia or paroxysmal AF and control (142)	The overall decline in active atrial contraction, indicated by the reduction in the end-diastolic SR difference and the peak diastolic SR difference adjusted for heart rate, was noted in individuals with hypertension and paroxysmal AF.
Thomas <i>et al</i> <sup>28</sup>	Atrial fibrillation patient and control (74)	The atrial strain obtained using Doppler decreased following cardioversion from persistent atrial fibrillation and gradually improved, although did not revert to normal levels.
Kurt <i>et al</i> <sup>26</sup>	Patients with indications for right heart hemodynamic assessment and control (91)	People with diastolic heart failure show significantly lower heart muscle strain and strain rate during contraction compared to those who have diastolic dysfunction without symptoms. Interestingly, patients with symptoms but no full heart failure have similar strain levels to those with diagnosed diastolic heart failure.
Modesto <i>et al</i> <sup>29</sup>	Amiloid and control (145)	Strain derived from Doppler and strain rate decreased among patients diagnosed with amyloidosis without involvement of additional echocardiographic features.
Inaba <i>et al</i> <sup>30</sup>	Atrial fibrillation and control (77)	Imaging obtained from Doppler allows for the assessment of LA dysfunction associated with aging and LA dilation.
Schneider <i>et al</i> <sup>31</sup>	Atrial fibrillation (118)	Patients with atrial strain derived from Doppler and higher SR following catheter ablation seem to have an increased probability of maintaining sinus rhythm.
Di Salvo <i>et al</i> <sup>32</sup>	Patient with lone AF no longer than 3 months (65)	There is a correlation between a higher probability of sustaining sinus rhythm and higher atrial pressure as determined by Doppler and strain rate after successful external cardioversion.
Wang <i>et al</i> <sup>33</sup>	Atrial fibrillation and control (69)	A reduced early diastolic strain rate, as assessed through Doppler imaging, serves as an independent and reliable predictor of unsuccessful cardioversion outcomes. This parameter provides prognostic value irrespective of other clinical variables and may be useful in patient selection or pre-procedural risk stratification.
Yu <i>et al</i> <sup>34</sup>	Heart failure patient (107)	The atrial strain rate from Doppler increases in patients who respond to resynchronization therapy.
<b>Research on 2D speckle tracking</b>		
Vianna-Pinton <i>et al</i> <sup>24</sup>	Normal subject (84)	Speckle tracking strain and strain rate can be used to measure regional LA contraction in healthy individuals of a broad age range. Thirteen left atrial segments were used to establish a set of benchmarks for strain and strain rate.
D'Andrea <i>et al</i> <sup>35</sup>	Dilated cardiomyopathy (314)	Systolic LA function is significantly diminished in idiopathic cardiomyopathy than in ischemic dilated cardiomyopathy.
D'Andrea <i>et al</i> <sup>23</sup>	Hypertensive patients, age-grouped athletes, and healthy sedentary volunteers (105)	The peak atrial systolic pressure significantly decreased in patients having pathological left ventricular hypertrophy in comparison with controls and athletes for all analyzed atrial segments.
D'Andrea <i>et al</i> <sup>36</sup>	Dilated cardiomyopathy (90)	Based on speckle-tracking strain analysis, ischemic dilated cardiomyopathy patients who responded to cardiac resynchronization therapy (CRT) demonstrated a significant enhancement in left atrial systolic function.
Cameli <i>et al</i> <sup>37</sup>	Healthy individual (60)	<i>Speckle tracking is a safe and easy technique to assess longitudinal LA myocardial deformation. The reference range for the strain index is reported in this study.</i>

relaxation ( $e'$ septal  $\leq 6$  cm/s or lateral  $\leq 7$  cm/s or Average  $\leq 6.5$  cm/s), followed by the evaluation of markers indicating of left atrial (LA)/LV remodeling and elevated left atrial pressure (LAP) (Average  $E/e' > 14$ , LARS  $\leq 18\%$ ,  $E/A \leq 0.8$  or  $\geq 2$ , LAVI  $> 34$  ml/m<sup>2</sup>). Normal values of left atrial strain vary depending on age; Age 20-39 years old (29.5 (27.6-31.3) to 63.2 (59.9-66.5)), 40-60 years old (26.8 (25.6-28.0) to 57.7 (55.6-59.9)) and 60-80 years old (24.1 (22.2-26.0) to 52.3 (48.9-55.7)). LARS  $\leq 18\%$  is correlated to elevated LAP. LARS  $\leq 18\%$  has high specificity but can have low sensitivity in patients with normal LVEF for detecting elevated LAP.<sup>42</sup>

#### Assessment of Left Atrial Function in Patients with Acute Heart Failure

The mechanical function of the left atrium (LA) in acute heart failure remains an area of limited investigation, both in terms of its underlying role in disease mechanisms and its potential value for predicting outcomes. The mechanical function of the left atrium (LA) is altered in individuals with acute heart failure who receive decongestive treatment. PALS and the LA reservoir strain rate show that decongestive medication and acute afterload reduction enhance LA reservoir

function.<sup>43</sup> In advanced heart failure—marked by reduced ejection fraction, elevated filling pressure, and low cardiac output—the peak atrial longitudinal strain (PALS) and the reservoir strain rate of the left atrium drop significantly, reflecting impaired reservoir function. Decongestive therapy was followed by a considerable improvement in PALS and LA reservoir strain rate within 6 weeks of hospital release. The pump strain rate, which reflects the left atrium's active contraction, didn't show meaningful improvement until six weeks after discharge—unlike PALS and reservoir strain rate, which improved earlier. Effective recovery time is necessary for the intrinsic atrial booster pump to function again. A better atrial booster pump function is associated to a lower value.

The left atrium does more than pass blood to the left ventricle during diastole—it plays an active, three-phase role throughout the cardiac cycle. It serves as a reservoir, a conduit, and a booster pump, all of which help support overall heart function.<sup>44,45</sup> It is crucial to highlight the continuous dynamic interaction between the LA and LV mechanisms in this instance. Because of the high LV filling pressure, the left atrium is extremely vulnerable to pressure and/or volume overload. Therefore, intrinsic atrial myopathy, changed loading conditions (such as hypertension or direct congestion), or insufficient compensatory mechanisms could be the cause of LA failure in the context of global heart failure. When the size of the LA grows with exposure to large filling volumes (LA preload) or pressure (LA afterload), the latter suggests a temporary increase in contractile shortening (Frank-Starling law at the atrial level). Ultimately, the contractile function of the LA decreases when the optimal threshold fiber-length is exceeded.<sup>46</sup> Deformation imaging in HFrEF has been used in a number of investigations to evaluate LA mechanics. In patients with advanced HFrEF, PALS is superior to  $E/e'$  as a predictor of LV end-diastolic pressure and has proven to be a strong prognostic indicator for rehospitalization due to heart failure and all-cause mortality in subjects.<sup>47</sup> Furthermore, the function of the LA reservoir is strongly correlated with the impaired functional capacity during Exercise.<sup>43</sup>

Peak Atrial Longitudinal Strain (PALS) has significant prognostic value in all heart failure phenotypes (HF reduced EF, HF mildly reduced EF, and HF preserved EF) in the context of acute heart failure. A large study conducted by Park JH et al. analyzed the echocardiography of patients in the STRATS-AHF registry. Patients with acute heart failure who face serious heart-related complications tend to have lower Peak Atrial Longitudinal Strain (PALS) values. In basic statistical analysis, PALS stands out as a strong predictor of outcomes. More importantly, multivariable analysis shows that for every 1% increase in PALS, the risk of adverse cardiovascular events drops by 1.6%, highlighting its prognostic value.<sup>48</sup> Peak longitudinal strain (PALS), measured during ventricular systole, is a key marker of left atrial (LA) reservoir function, reflecting the atrium's ability to store pulmonary venous return while the mitral valve remains closed. Several factors influence PALS values. LA volume, or preload, can increase strain through greater atrial stretch. Afterload, estimated by the  $E/e'$  ratio, reflects left ventricular (LV) filling pressures—higher pressures tend to reduce atrial deformation. The efficiency of LV systolic function also affects PALS, as impaired contraction may diminish atrial filling and movement. Lastly, LA fibrosis reduces tissue compliance, leading to lower strain values. Taken together, these variables make PALS a valuable, integrative measure in echocardiographic assessment of cardiac function.<sup>49</sup> Left atrial (LA) strain analysis is a useful tool for predicting atrial fibrillation (AF), especially the transition to persistent forms, as well as the risk of future embolic events. Beyond arrhythmia prediction, LA strain also offers prognostic insight in a range of cardiovascular conditions, including heart failure, acute myocardial infarction, and significant valvular disease.

### 3. Conclusion

The assessment of left atrial (LA) function through echocardiography has become a valuable prognostic tool for acute decompensated heart failure. LA strain analysis, particularly Peak Atrial Longitudinal Strain (PALS), demonstrates significant prognostic value across all heart failure phenotypes. The dynamic nature of LA function during treatment is highlighted by research showing a considerable improvement in PALS and LA reservoir strain rate following decongestive therapy. Each 1% increase in PALS correlates with a 1.6% reduction in adverse cardiovascular events, making it a more potent predictor than traditional measures like  $E/e'$  ratio. As the understanding

of LA mechanics evolves beyond viewing it as a passive chamber, echocardiographic assessment of LA strain shows promise as an essential imaging biomarker for risk stratification and therapeutic guidance in heart failure management.

### 4. Declaration

#### 4.1 Ethics Approval and Consent to participate

Patient has provided written informed consent prior to involvement in the study.

#### 4.2. Consent for publication

Not applicable.

#### 4.3 Availability of data and materials

Data used in our study were presented in the main text.

#### 4.4 Competing interests

Not applicable.

#### 4.5 Funding Source

Not applicable.

#### 4.6 Authors contributions

Idea/concept: NAN. Design: NAN. Control/supervision: NK, IP, WK, AF. Data collection/processing: NAN, WK, IP. Analysis/interpretation: NAN, WK, IP. Literature review: NAN, WK, IP, AF. Writing the article: NAN. Critical review: NAN, IP, WK, AF.

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### References

- McDonagh TA, Metra M, Adamo M, Gardner RS, Baumbach A, Bohm M, et al. 2021 ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure: Developed by the Task Force for the diagnosis and treatment of acute and chronic heart failure of the European Society of Cardiology (ESC). With the special contribution of the Heart Failure Association (HFA) of the ESC. *Eur J Heart Fail* 2022;24 (1):4-131. doi: 10.1002/ehfj.2333.
- Blume GG, McLeod CJ, Barnes ME, Seward JB, Pellikka PA, Bastiansen PM, et al. Left atrial function: physiology, assessment, and clinical implications. *Eur J Echocardiogr* 2011;12 (6):421-430. doi: 10.1093/ejechocard/jeq175.
- Benjamin EJ, D'Agostino RB, Belanger AJ, Wolf PA, Levy D. Left atrial size and the risk of stroke and death. The Framingham Heart Study. *Circulation* 1995;92 (4):835-841. doi: 10.1161/01.cir.92.4.835.
- Laukkanen JA, Kurl S, Eranen J, Huttunen M, Salonen JT. Left atrium size and the risk of cardiovascular death in middle-aged men. *Arch Intern Med* 2005;165 (15):1788-1793. doi: 10.1001/archinte.165.15.1788.
- Abhayaratna WP, Seward JB, Appleton CP, Douglas PS, Oh JK, Tajik AJ, et al. Left atrial size: physiologic determinants and clinical applications. *J Am Coll Cardiol* 2006;47 (12):2357-2363. doi: 10.1016/j.jacc.2006.02.048.
- Tsang TS, Abhayaratna WP, Barnes ME, Miyasaka Y, Gersh BJ, Bailey KR, et al. Prediction of cardiovascular outcomes with left atrial size: is volume superior to area or diameter? *J Am Coll Cardiol* 2006;47 (5):1018-1023. doi: 10.1016/j.jacc.2005.08.077.
- Thomas L, Abhayaratna WP. Left Atrial Reverse Remodeling: Mechanisms, Evaluation, and Clinical Significance. *JACC Cardiovasc Imaging* 2017;10 (1):65-77. doi: 10.1016/j.jcmg.2016.11.003.
- Khan MS, Memon MM, Murad MH, Vaduganathan M, Greene SJ, Hall M, et al. Left atrial function in heart failure with preserved ejection fraction: a systematic review and meta-analysis. *Eur J Heart Fail* 2020;22 (3):472-485. doi: 10.1002/ehfj.1643.

9. Inciardi RM, Bonelli A, Biering-Sorensen T, Cameli M, Pagnesi M, Lombardi CM, et al. Left Atrial Disease and Left Atrial Reverse Remodelling Across Different Stages of Heart Failure Development and Progression: A New Target for Prevention and Treatment. *European Journal of Heart Failure* 2022;24 (6):959-975. doi: 10.1002/ehf2.2562.
10. Ponikowski P, Anker SD, AlHabib KF, Cowie MR, Force TL, Hu S, et al. Heart failure: preventing disease and death worldwide. *ESC Heart Fail* 2014;1 (1):4-25. doi: 10.1002/ehf2.12005.
11. Reyes EB, Ha JW, Firdaus I, Ghazi AM, Phrommintikul A, Sim D, et al. Heart failure across Asia: Same healthcare burden but differences in organization of care. *Int J Cardiol* 2016;223 (1):163-167. doi: 10.1016/j.ijcard.2016.07.256.
12. Kementerian Kesehatan Republik I. Laporan Risdas 2018 Nasional. Jakarta: Lembaga Penerbit Balitbangkes; 2018.
13. Kamila P, Rohman M, Anjarwani S, Sargowo D, Rahimah A, Prasetya I, et al. The Added Value of Bioimpedance Analysis to NT-proBNP in Predicting Short-term outcome in Acute Heart Failure Patients. *Heart Science Journal* 2021;2 (1):36-40. doi: 10.21776/ub.hsj.2021.002.01.06.
14. Bozkurt B, Coats AJ, Tsutsui H, Abdelhamid M, Adamopoulos S, Albert N, et al. Universal Definition and Classification of Heart Failure: A Report of the Heart Failure Society of America, Heart Failure Association of the European Society of Cardiology, Japanese Heart Failure Society and Writing Committee of the Universal Definition of Heart Failure. *J Card Fail* 2021;27 (4):387-413. doi: 10.1016/j.cardfail.2021.01.022.
15. Arrigo M, Jessup M, Mullens W, Reza N, Shah AM, Sliwa K, et al. Acute heart failure. *Nat Rev Dis Primers* 2020;6 (1):16. doi: 10.1038/s41572-020-0151-7.
16. Pagel P, Kehl F, Gare M, Hettrick D, Kersten J. New Insights Based on Analysis of Pressure-Volume Relations and Doppler. *American Society of Anesthesiologists* 2003;98 (4):975-994. doi: 10.1016/j.jacc.2007.04.073.
17. Appleton CP, Hatle LK, Popp RL. Relation of transmitral flow velocity patterns to left ventricular diastolic function: new insights from a combined hemodynamic and Doppler echocardiographic study. *J Am Coll Cardiol* 1988;12 (2):426-440. doi: 10.1016/0735-1097(88)90416-0.
18. Stefanadis C, Dernellis J, Toutouzas P. A clinical appraisal of left atrial function. *Eur Heart J* 2001;22 (1):22-36. doi: 10.1053/euhj.1999.2581.
19. Blondheim DS, Osipov A, Meisel SR, Frimerman A, Shochat M, Shotan A. Relation of left atrial size to function as determined by transesophageal echocardiography. *Am J Cardiol* 2005;96 (3):457-463. doi: 10.1016/j.amjcard.2005.03.101.
20. Thomas L, Levett K, Boyd A, Leung DY, Schiller NB, Ross DL. Compensatory changes in atrial volumes with normal aging: is atrial enlargement inevitable? *J Am Coll Cardiol* 2002;40 (9):1630-1635. doi: 10.1016/s0735-1097(02)02371-9.
21. Pathak R, Lau DH, Mahajan R, Sanders P. Structural and Functional Remodeling of the Left Atrium: Clinical and Therapeutic Implications for Atrial Fibrillation. *J Atr Fibrillation* 2013;6 (4):986. doi: 10.4022/jafib.986.
22. Pérez-Paredes M, González M, Ruiz Ros JA, Giménez DM, Carnero A, Carrillo A, et al. Assessment of Left Atrial Wall Velocities by Pulsed Wave Tissue Doppler Imaging. A New Approach to the Study of Atrial Function. *Revista Española de Cardiología (English Edition)* 2004;57 (11):1059-1065. doi: https://doi.org/10.1016/S1885-5857(06)60192-8.
23. D'Andrea A, De Corato G, Scarafile R, Romano S, Reigler L, Mita C, et al. Left atrial myocardial function in either physiological or pathological left ventricular hypertrophy: a two-dimensional speckle strain study. *Br J Sports Med* 2008;42 (8):696-702. doi: 10.1136/bjism.2007.041210.
24. Vianna-Pinton R, Moreno CA, Baxter CM, Lee KS, Tsang TS, Appleton CP. Two-dimensional speckle-tracking echocardiography of the left atrium: feasibility and regional contraction and relaxation differences in normal subjects. *J Am Soc Echocardiogr* 2009;22 (3):299-305. doi: 10.1016/j.echo.2008.12.017.
25. Thomas JD, Edvardsen T, Abraham T, Appadurai V, Badano L, Banchs J, et al. Clinical Applications of Strain Echocardiography: A Clinical Consensus Statement From the American Society of Echocardiography Developed in Collaboration With the European Association of Cardiovascular Imaging of the European Society of Cardiology. *J Am Soc Echocardiogr* 2025;38 (11):985-1020. doi: 10.1016/j.echo.2025.07.007.
26. Kurt M, Wang J, Torre-Amione G, Nagueh SF. Left atrial function in diastolic heart failure. *Circ Cardiovasc Imaging* 2009;2 (1):10-15. doi: 10.1161/CIRCIMAGING.108.813071.
27. Wang Z, Tan Hw, Zhong M, Jiang G-h, Zhang Y, Zhang W. Strain Rate Imaging for Noninvasive Functional Quantification of the Left Atrium in Hypertensive Patients with Paroxysmal Atrial Fibrillation. *Cardiology* 2007;109 (1):15 - 24. doi: 10.1093/eurheartj/ehi040.
28. Thomas L, Mckay T, Byth K, Marwick TH. Abnormalities of left atrial function after cardioversion: an atrial strain rate study. *Heart* 2007;93 (1):89-95. doi: 10.1136/hrt.2006.088609.
29. Modesto KM, Dispenzieri A, Cauduro SA, Lacy M, Khandheria BK, Pellikka PA, et al. Left atrial myopathy in cardiac amyloidosis: implications of novel echocardiographic techniques. *European Heart Journal* 2004;26 (2):173-179. doi: 10.1093/eurheartj/ehi040.
30. Inaba Y, Yuda S, Kobayashi N, Hashimoto A, Uno K, Nakata T, et al. Strain rate imaging for noninvasive functional quantification of the left atrium: comparative studies in controls and patients with atrial fibrillation. *J Am Soc Echocardiogr* 2005;18 (7):729-736. doi: 10.1016/j.echo.2004.12.005.
31. Schneider C, Malisius R, Krause K, Lampe F, Bahlmann E, Boczor S, et al. Strain rate imaging for functional quantification of the left atrium: atrial deformation predicts the maintenance of sinus rhythm after catheter ablation of atrial fibrillation. *European Heart Journal* 2008;29 (11):1397-1409. doi: 10.1093/eurheartj/ehn168.
32. Di Salvo G, Caso P, Lo Piccolo R, Fusco A, Martiniello AR, Russo MG, et al. Atrial myocardial deformation properties predict maintenance of sinus rhythm after external cardioversion of recent-onset lone atrial fibrillation: a color Doppler myocardial imaging and transthoracic and transesophageal echocardiographic study. *Circulation* 2005;112 (3):387-395. doi: 10.1161/CIRCULATIONAHA.104.463125.
33. Wang T, Wang M, Fung JW, Yip GW, Zhang Y, Ho PP, et al. Atrial strain rate echocardiography can predict success or failure of cardioversion for atrial fibrillation: a combined transthoracic tissue Doppler and transoesophageal imaging study. *Int J Cardiol* 2007;114 (2):202-209. doi: 10.1016/j.ijcard.2006.01.051.
34. Yu CM, Fang F, Zhang Q, Yip GW, Li CM, Chan JY, et al. Improvement of atrial function and atrial reverse remodeling after cardiac resynchronization therapy for heart failure. *J Am Coll Cardiol* 2007;50 (8):778-785. doi: 10.1016/j.jacc.2007.04.073.
35. D'Andrea A, Caso P, Romano S, Scarafile R, Cuomo S, Salerno G, et al. Association between left atrial myocardial function and exercise capacity in patients with either idiopathic or ischemic dilated cardiomyopathy: a two-dimensional speckle strain study. *Int J Cardiol* 2009;132 (3):354-363. doi: 10.1016/j.ijcard.2007.11.102.
36. D'Andrea A, Caso P, Romano S, Scarafile R, Riegler L, Salerno G, et al. Different effects of cardiac resynchronization therapy on left atrial function in patients with either idiopathic or ischaemic dilated cardiomyopathy: a two-dimensional speckle strain study. *Eur Heart J* 2007;28 (22):2738-2748. doi: 10.1093/eurheartj/ehm443.

37. Cameli M, Caputo M, Mondillo S, Ballo P, Palmerini E, Lisi M, et al. Feasibility and reference values of left atrial longitudinal strain imaging by two-dimensional speckle tracking. *Cardiovasc Ultrasound* 2009;7 (1):6. doi: 10.1186/1476-7120-7-6.
38. Thomas JD, Edvardsen T, Abraham T, Appadurai V, Badano L, Banchs J, et al. Clinical Applications of Strain Echocardiography: A Clinical Consensus Statement From the American Society of Echocardiography Developed in Collaboration With the European Association of Cardiovascular Imaging of the European Society of Cardiology. *Eur Heart J Cardiovasc Imaging* 2026;27 (3):335-368. doi: 10.1093/ehjci/jeag006.
39. Wakami K, Ohte N, Asada K, Fukuta H, Goto T, Mukai S, et al. Correlation between left ventricular end-diastolic pressure and peak left atrial wall strain during left ventricular systole. *J Am Soc Echocardiogr* 2009;22 (7):847-851. doi: 10.1016/j.echo.2009.04.026.
40. Tomlinson S, Scalia GM, Appadurai V, Edwards N, Savage M, Lam AK, et al. Left atrial reservoir strain provides incremental value to left atrial volume index for evaluation of left ventricular filling pressure. *Echocardiography* 2021;38 (9):1503-1513. doi: 10.1111/echo.15157.
41. Inoue K, Khan FH, Remme EW, Ohte N, Garcia-Izquierdo E, Chetrit M, et al. Determinants of left atrial reservoir and pump strain and use of atrial strain for evaluation of left ventricular filling pressure. *Eur Heart J Cardiovasc Imaging* 2021;23 (1):61-70. doi: 10.1093/ehjci/jeaa415.
42. Nagueh SF, Sanborn DY, Oh JK, Anderson B, Billick K, Derumeaux G, et al. Recommendations for the Evaluation of Left Ventricular Diastolic Function by Echocardiography and for Heart Failure With Preserved Ejection Fraction Diagnosis: An Update From the American Society of Echocardiography. *J Am Soc Echocardiogr* 2025;38 (7):537-569. doi: 10.1016/j.echo.2025.03.011.
43. Deferm S, Martens P, Verbrugge FH, Bertrand PB, Dauw J, Verhaert D, et al. LA Mechanics in Decompensated Heart Failure: Insights From Strain Echocardiography With Invasive Hemodynamics. *JACC Cardiovasc Imaging* 2020;13 (5):1107-1115. doi: 10.1016/j.jcmg.2019.12.008.
44. Hoit BD. Left Atrial Size and Function. *JACC* 2014;63 (6):493-505. doi: doi:10.1016/j.jacc.2013.10.055.
45. Triposkiadis F, Pieske B, Butler J, Parissis J, Giamouzis G, Skoularigis J, et al. Global left atrial failure in heart failure. *Eur J Heart Fail* 2016;18 (11):1307-1320. doi: 10.1002/ehfj.645.
46. Payne RM, Stone HL, Engelken EJ. Atrial function during volume loading. *J Appl Physiol* 1971;31 (3):326-331. doi: 10.1152/jappl.1971.31.3.326.
47. Barki M, Losito M, Caracciolo MM, Sugimoto T, Roviada M, Viva T, et al. Left atrial strain in acute heart failure: clinical and prognostic insights. *Eur Heart J Cardiovasc Imaging* 2024;25 (3):315-324. doi: 10.1093/ehjci/jead287.
48. Park JH, Hwang IC, Park JJ, Park JB, Cho GY. Prognostic power of left atrial strain in patients with acute heart failure. *Eur Heart J Cardiovasc Imaging* 2021;22 (2):210-219. doi: 10.1093/ehjci/jeaa013.
49. Kuppahally SS, Akoum N, Burgon NS, Badger TJ, Kholmovski EG, Vijayakumar S, et al. Left atrial strain and strain rate in patients with paroxysmal and persistent atrial fibrillation: relationship to left atrial structural remodeling detected by delayed-enhancement MRI. *Circ Cardiovasc Imaging* 2010;3 (3):231-239. doi: 10.1161/CIRCIMAGING.109.865683.