Review Article

My Approach to Left Atrial Function: From Basic Assessment to Atrial Stiffness

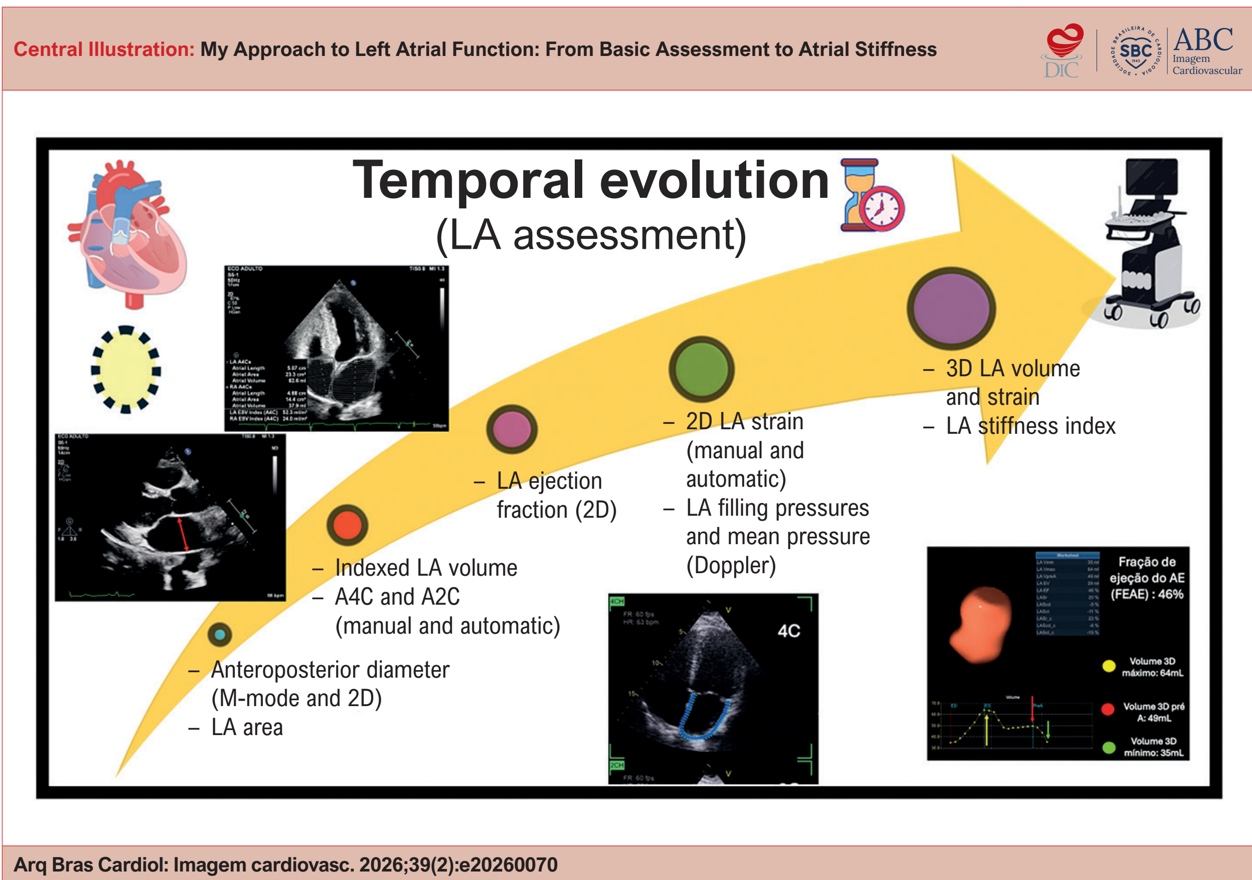
***Halsted Alarcão Gomes Pereira da Silva,*[1] *Helder Moura Gomes,*[2] *Alexandre Costa Souza*[3]**

Hospital São Geraldo,[1] Juína, MT – Brazil

Hospital Metropolitano Dom José Maria Pires,[2] João Pessoa, PB – Brazil

Hospital São Rafael,[3] Salvador, BA – Brazil

Central Illustration: My Approach to Left Atrial Function: From Basic Assessment to Atrial Stiffness



Arq Bras Cardiol: Imagem cardiovasc. 2026;39(2):e20260070

Temporal evolution of integrated left atrial analysis: a practical illustration of the technological evolution of echocardiography in the assessment of left atrial function. 2D: two-dimensional; 3D: three-dimensional; A2C: apical two-chamber view; A4C: apical four-chamber view; LA: left atrium.

Keywords

Strain, Left atrium; Ejection fraction

Mailing Address: Halsted Alarcão Gomes Pereira da SilvaX •
Instituto Dante Pazzanese de Cardiologia. Rua Dr Dante Pazzanese, 500. Postal code: 04012-909. São Paulo, SP – Brazil
E-mail: halstedufg@hotmail.com
Manuscript received May 4, 2026, revised manuscript May 4, 2026, accepted May 4, 2026
Editor responsible for the review: Marcelo Tavares

DOI: https://doi.org/10.36660/abcimg.20260070i

Abstract

The left atrium (LA) has historically been considered a passive chamber that conducts blood flow between the pulmonary veins and the left ventricle (LV). Advances in cardiovascular physiology and imaging techniques have highlighted its active role in modulating cardiac output, ventricular diastolic function, and the stratification of various heart diseases. Assessment of the LA has evolved over the years into a multiparametric functional approach, consolidated as an essential component of

modern echocardiography. The systematic incorporation of volumetric parameters, atrial strain, and atrial stiffness allows for a more precise characterization of cardiovascular pathophysiology and improves prognostic stratification, thus supporting more informed clinical decisions.

Introduction

For many years, the left atrium (LA) was analyzed solely as a segment of transition between the pulmonary veins and the left ventricle (LV), traditionally considered the primary pump of the heart. Over time, with a better understanding of the physiology of systolic and diastolic flows, this concept has given way to that of a chamber that plays a fundamental role in maintaining adequate cardiac output. It has likewise been established that alterations related to the LA directly influence pulmonary pressures and right chamber hemodynamics.

This review article provides a discussion ranging from the most basic concepts related to the LA to the new frontiers that have recently emerged with the understanding of the complex mechanics of this chamber in relation to cardiac function (Central Illustration).

Left atrial function and anatomy

The LA is located in the most posterior position of the heart, posterior and slightly superior to the right atrium (RA). It is separated from the RA by a fibromuscular wall called the interatrial septum. The posterior part of the LA is smooth and generally receives four pulmonary veins (two superior and two inferior), which return oxygenated blood from the lungs. The anterior portion of the LA is trabeculated and contains pectinate muscles, which are less numerous than those of the RA.

The LA fulfills three main physiological functions that influence the filling and performance of the LV (Figure 1).[1]

1. **Reservoir function:** During this phase, the LA functions as a reservoir, receiving blood from the pulmonary veins. It begins with the closure of the mitral valve (isovolumetric contraction), encompassing ventricular systole, and extends until isovolumetric relaxation.
   – **Main modulators:** The reservoir function of the LA is modulated by both biventricular contraction and LA compliance (chamber relaxation and stiffness).
2. **Conduit function:** During this phase, the LA acts as a conduit, with flow occurring passively, originating in the pulmonary veins and directed towards the LV. It begins immediately after mitral valve opening, encompassing the initial ventricular relaxation period and diastasis. It ends shortly before atrial contraction (P wave on the electrocardiogram).
   – **Main modulators:** The conduit function of the LA is predominantly modulated by LV relaxation and compliance, as well as early diastolic pressures.
3. **Contractile function:** During the contraction phase, the LA empties actively, contributing 20% to 30% of cardiac output in the absence of heart disease. This phase begins at the end of ventricular diastole, during the atrial contraction period.
   – **Main modulators:** LA contractile function is predominantly modulated by LV end-diastolic pressure and the intrinsic contractility of the LA.

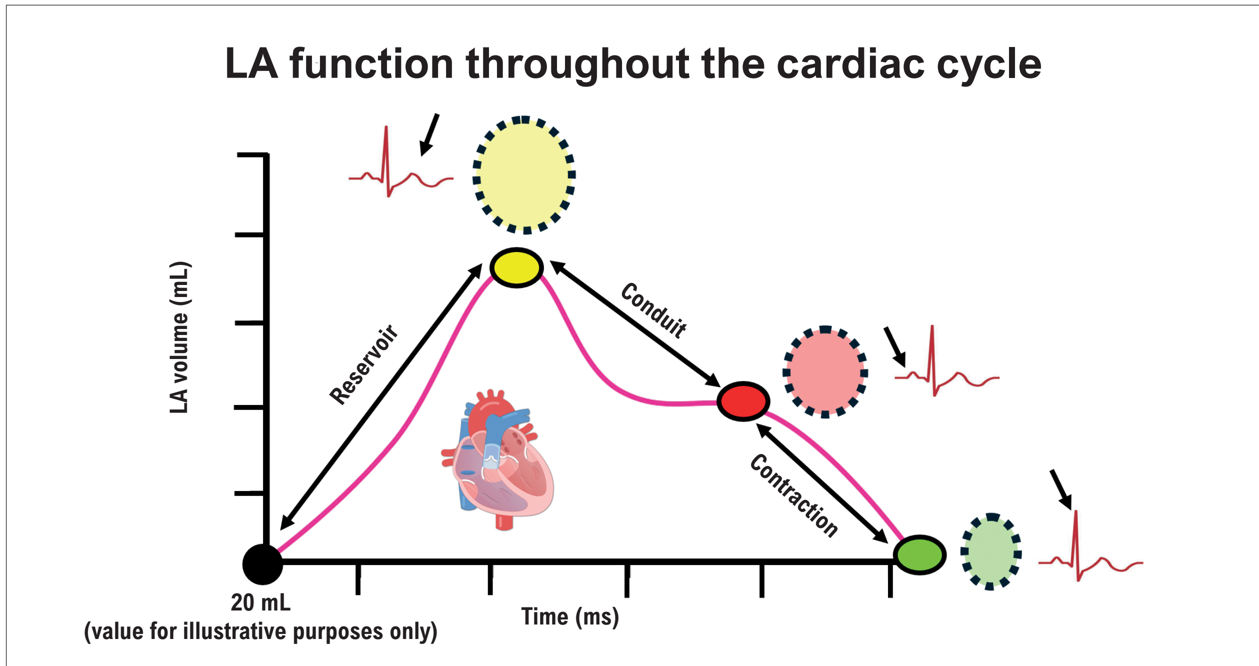


Figure 1 – *Phases of left atrial function throughout the cardiac cycle. The reservoir, conduit, and contraction phases are shown considering a volume × time curve. LA: left atrium. Source: The authors.*

There is currently extensive literature supporting the understanding of the prognostic correlation between LA function and maximum volume in diverse conditions, including atrial fibrillation (AF), heart failure (HF), coronary artery disease, mitral regurgitation, mitral stenosis, diastolic dysfunction, stroke, hypertrophic cardiomyopathy, and chronic kidney disease.[2] These data are essential for correct anatomical and functional characterization of this chamber during echocardiographic examination, avoiding erroneous diagnoses and inadequate treatment.

Linear dimensions and area measurements

The first method for quantifying LA dimensions was derived from linear measurements performed using M-mode. This parameter was fundamental for establishing normality and follow-up values, allowing studies to be conducted with more regular measurements and low variability in longitudinal follow-up. The most widely used linear dimension measurement is the anteroposterior diameter of the LA in the parasternal longitudinal axis, initially using M-mode echocardiography, subsequently performed using anatomical M-mode, and more recently guided by two-dimensional (2D) echocardiography.

It is worth noting that assessment of LA size using only the anteroposterior diameter assumes that, when the LA increases in size, all of its dimensions change proportionally, which is often not the case during atrial remodeling.

LA area has emerged as a more accurate analytical parameter than anteroposterior diameter for quantifying the size of both the LA and RA. For this measurement, atrial area planimetry should be performed in the apical two- and four-chamber views. Normal values for these cavities have been standardized and established over the years (LA ≤ 20 cm² and RA ≤ 18 cm²). Despite this improved accuracy in relation to diameter measurement, area assessment has not been shown to be a perfect substitute given that atrial volume is the ultimate measurement to be obtained. With the progressive improvement of 2D imaging, associated with the automation of volume acquisition and the more robust literature on normal values and prognostic data of atrial volumes, it is currently unnecessary to include LA area in the final report.[1]

2D echocardiographic assessment of left atrial volumes

Assessment of volumes and their prognostic correlation is supported by robust scientific evidence. Considerations regarding their acquisition and measurement are fundamental to avoid errors in measurement and consequent clinical interpretation.

First, it is necessary to understand that the longitudinal axes of the LV and LA often lie in different planes; consequently, dedicated LA acquisitions from the apical window should be obtained for more reliable measurements of atrial volume. The LA base should be visualized at its maximal diameter, indicating that the image plane passes through the maximum area of the central axis. The length should also be maximized to ensure correct alignment along the true axis of the LA (Figure 2).[1]

Length is measured from the mitral annulus to the superior wall of the LA. Long-axis lengths should not vary by more than 5 mm between the two echocardiographic views. If this variation is greater than 5 mm, the apical images should be reassessed. When tracing the endocardial borders, the LA appendage and pulmonary veins should be excluded from final analysis.[3]

Most ultrasound systems automatically calculate biplanar LA volume, after correctly delineating the atrial endocardium, using both the area-length method and the disc summation method (modified Simpson). For the area-length method, the shorter length obtained (in the two- or four-chamber view) is used to calculate LA volume. In contrast, for the disc summation method, the longer of the two measured lengths is used. It is worth noting that

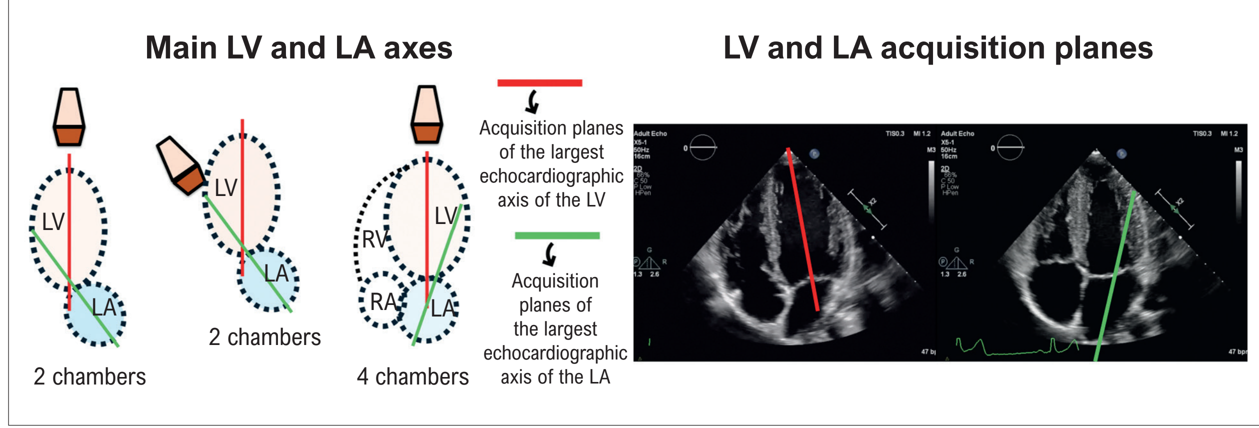


Figure 2 – *Dedicated echocardiographic acquisition of the LA. Left: A schematic drawing of the acquisition planes of the largest LA and LV axes. Right: The same schematic representation on 2D echocardiography in apical two- and four-chamber views. The longitudinal axes drawn for the LA (green line) and the LV (red line) are situated in different planes. LA: left atrium; LV: left ventricle; RA: right atrium; RV: right ventricle. Source: The authors.*

the area-length method consistently produces larger LA volumes than the disk summation method.[1]

The American Society of Echocardiography currently recommends the disk summation method for calculating LA volume, as it involves fewer geometric assumptions about LA shape. More recently, the semi-automated use of endocardial border tracking has provided volumes that correlate well with volumes acquired by three-dimensional (3D) echocardiography, computed tomography (CT), and cardiac magnetic resonance imaging (CMR), demonstrating lower interobserver variability than manual tracing. It is worth emphasizing that, despite the correlation, 2D echocardiographic volumes will always yield smaller values than those acquired by 3D methods. Given that volume calculation varies according to the technique, it is important for laboratories to consistently use the same technique.[1,4,5]

Patient size is one of the main determinants of LA size, and absolute LA volumes are larger in men than in women; therefore, indexing by body surface area partially corrects for this variability. Since 2015, the American Society of Echocardiography guideline for cardiac chamber quantification considers LA volume index values > 34 mL/m² to be abnormal. This value was based on observational studies with more than 6,000 patients without a history of AF or valvular heart disease, demonstrating that an indexed volume above 34 mL/m² was an independent predictor of death, HF, AF, and stroke (Figure 3).[6]

The main issue with the currently recommended grading values for LA volume (mildly enlarged = 35 to 41 mL/m², moderately enlarged = 42 to 48 mL/m², and severely enlarged > 48 mL/m²) is the narrow range between different categories. Consequently, even small measurement errors can result in incorrect classification of the degree of LA enlargement.[1]

A study published by Esther et al. in the *Journal of the American College of Cardiology* in 2022 demonstrated greater accuracy in classifying and stratifying LA dilation when using height-indexed and height-squared values in patients with overweight or obesity. Using individual data from over 17,000 patients, the use of height-indexed values reclassified LA abnormalities in up to 28% of patients when compared to indexing by body surface area, the parameter classically used in clinical practice. Table 1 displays normal values for these parameters.[7]

These calculations, even with the various additional indexing corrections, still consider geometric assumptions that underestimate the final volume, which should also be considered in interpretation.[1,4,5]

2D echocardiographic assessment of left atrial ejection fraction

After accurate volumetric acquisition of the LA during the cardiac cycle, an important parameter of atrial function can be obtained, namely, left atrial ejection fraction (LAEF). As shown in Figure 4,[1] LAEF, similar to LV ejection fraction, is calculated considering volumetric variation in different phases, at the following three moments of the cardiac cycle:

- **Atrial volume at the end of ventricular systole:** maximum LA volume (LAVmax)
- **Atrial volume immediately before atrial contraction:** LA volume before the P wave (LAVpreA)

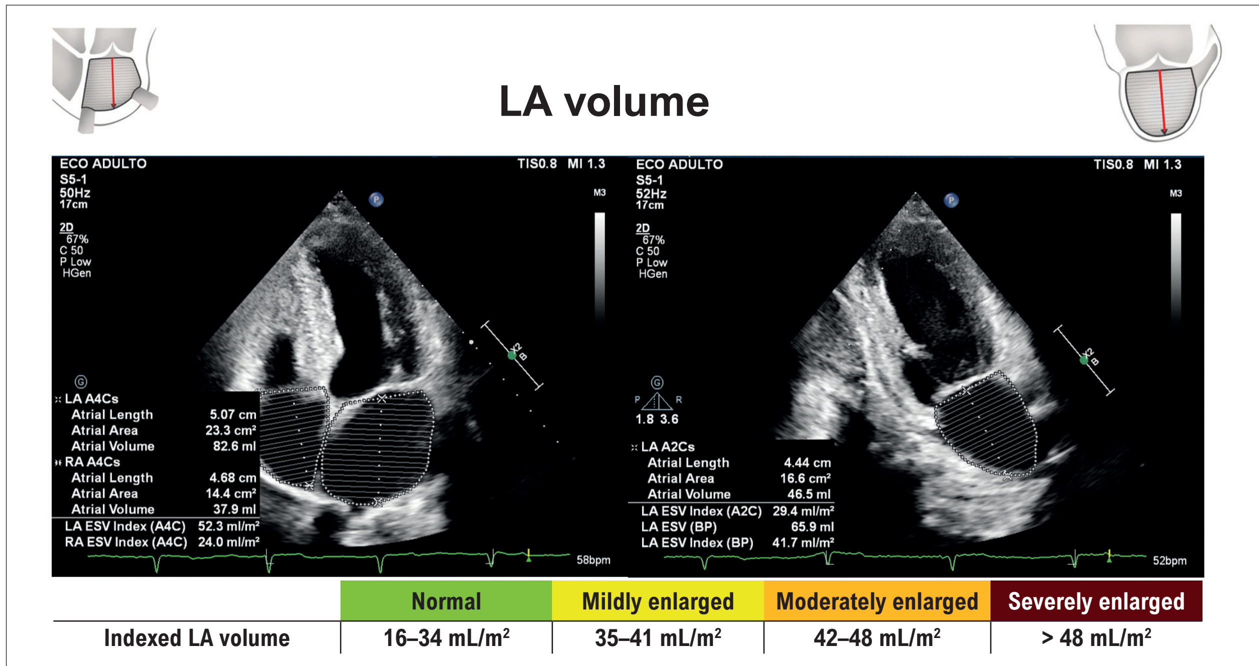


Figure 3 – *Calculation of left atrial volume using the biplane method (Simpson) and grading of enlargement according to the 2015 American Society of Echocardiography Guideline. LA: left atrium.*

Table 1 – Normal and left atrial dilation values, considering body surface area, height, and height squared

	Normal values	LA dilation
LA volume indexed by body surface area	Men: ≤ 34 mL/m² Women: ≤ 34 mL/m²	Men: ≥ 35 mL/m² Women: ≥ 35 mL/m²
LA volume indexed by height	Men: ≤ 35.7 mL/m Women: ≤ 33.7 mL/m	Men: ≥ 35.8 mL/m Women: ≥ 33.8 mL/m
LA volume indexed by height²	Men: ≤ 18.5 mL/m² Women: ≤ 16.5 mL/m²	Men: ≥ 18.6 mL/m² Women: ≥ 16.6 mL/m²

LA: left atrium. Adapted from Davis et al. J Am Coll Cardiol Img, 2022.[7]

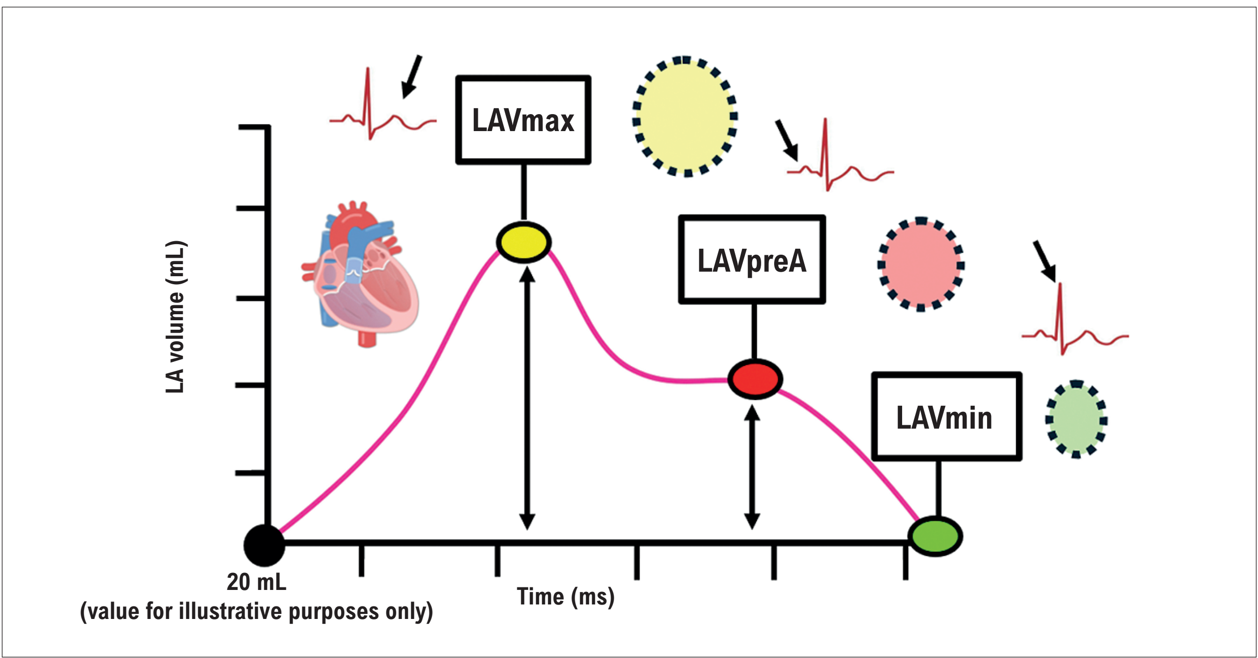


Figure 4 – *Left atrial volumes throughout the cardiac cycle: LAVmax (end of T wave), LAVpreA (before P wave), and LAVmin (R wave). LA: left atrium; LAVmax: maximum left atrial volume; LAVmin: minimum left atrial volume; LAVpreA: left atrial volume immediately before atrial contraction.*

- **Atrial volume at the end of ventricular diastole:** minimum LA volume (LAVmin).

Based on these volumes, the following three main values are obtained: total ejection fraction (reservoir) derived from LAVmax and LAVmin, passive ejection fraction (conduit) derived from LAVmax and LAVpreA, and active ejection fraction (contraction) derived from LAVpreA and LAVmin, according to the formulas below:[1]

1. **Total LAEF (global reservoir function) = (LAVmax – LAVmin) / LAVmax × 100**
2. **Passive LAEF = (LAVmax – LAVpreA) / LAVmax × 100**
3. **Active LAEF = (LAVpreA – LAVmin) / LAVpreA × 100**

Note: In the literature, ejection fraction and emptying fraction can be found as equivalent terms.

Figure 5 illustrates an example of LA volume calculation, as well as the derivation of LAEF, which showed the strongest prognostic correlation in most studies.[1,8]

It is worth noting that the active ejection fraction, as it depends on atrial contraction, cannot be assessed in the absence of sinus rhythm.

These parameters can be assessed using different imaging techniques: 2D and 3D echocardiography, CT, or CMR. Using dedicated software for quantifying LA volume, volumetric and functional assessment at different stages has become more accurate, reproducible, and less time-consuming compared to classic 2D analysis.

Tables 2 and 3 show the normal values for LA volumes and function according to published data from a study conducted by the World Alliance Societies of

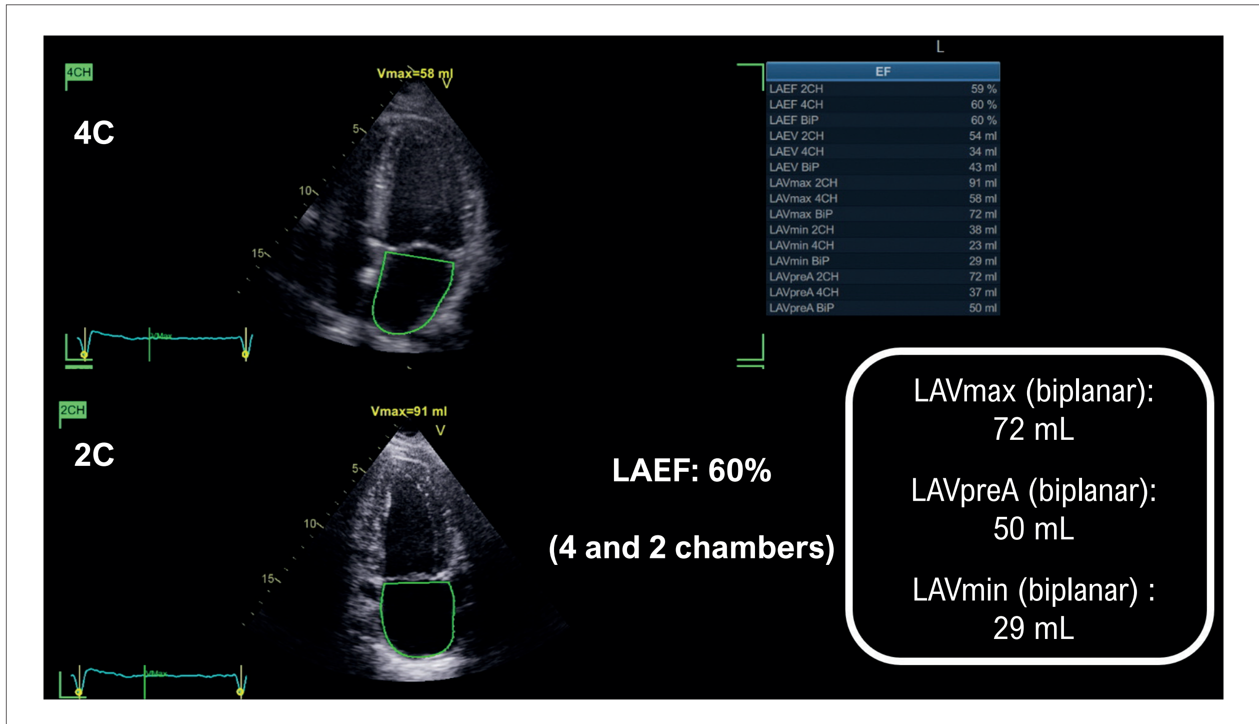


Figure 5 – *Biplane tracing of the LA and calculation of the total ejection fraction, which in this case is preserved. 2C: two-chamber view; 4C: four-chamber view; LA: left atrium; LAEF: left atrial ejection fraction; LAVmax: maximum left atrial volume; LAVmin: minimum left atrial volume; LAVpreA: left atrial volume immediately before atrial contraction.*

Table 2 – Comparison of left atrial volumetric and functional parameters between 2D and 3D methods (WASE Study, 2022)

Normal values for LA size and function derived from 1,765 healthy adults (results from the World Alliance Societies of Echocardiography Study)		
Volume parameters	**2D**	**3D**
Maximum volume (mL)	45.9 ± 15.7	49.9 ± 14.1
Maximum indexed volume (mL/m²)	25.7 ± 7.9	28.1 ± 6.9
Minimum volume (mL)	*	19.0 ± 7.2
Minimum indexed volume (mL/m²)	*	10.7 ± 3.7
Pre-A volume (mL/m²)	*	31.6 ± 10.8
Indexed pre-A volume (mL/m²)	*	17.8 ± 5.5
Reservoir volume (mL)	*	30.9 ± 9.0
Indexed reservoir volume (mL/m²)	*	17.4 ± 4.5
Conduit volume (mL)	*	18.4 ± 6.4
Indexed conduit volume (mL/m²)	*	10.4 ± 3.4

*Values are shown as mean ± standard deviation. 2D: two-dimensional echocardiography; 3D: three-dimensional echocardiography; LA: left atrium; pre-A: immediately before atrial contraction. *Data not provided by WASE, 2022.*

Table 3 – Reference values for left atrial volumes and ejection fractions (WASE Study, 2022)

Normal values for LA size and function derived from 1,765 healthy adults (results from the World Alliance Societies of Echocardiography Study)		
Function parameters	**2D**	**3D**
Ejection fraction (%)	65.7 ± 8.4	62.2 ± 7.7
Passive ejection fraction (%)	*	37.7 ± 11.0
Active ejection fraction (%)	*	39.5 ± 9.5
Reservoir strain (%)	42.1 ± 10.0	*
Conduit strain (%)	27.7 ± 9.7	*
Contractile strain (%)	14.4 ± 6.3	*

*Values are shown as mean ± standard deviation.2D: two-dimensional echocardiography; 3D: three-dimensional echocardiography; LA: left atrium. * Data not provided by WASE, 2022.*

Echocardiography. Despite these international data, it is important to emphasize that reference values for analysis of atrial function by 2D and 3D methods have not yet been standardized and incorporated into echocardiography guidelines.[9]

In patients with severe aortic stenosis, LAEF has proven useful for prognostic assessment. Cutoff values below 37% have shown superiority even in relation to maximum velocity and mean gradient for predicting mortality.[10]

Regarding arrhythmias, when evaluating only patients with AF, reduced LAEF was associated with worse cardiovascular outcomes, regardless of LV ejection fraction.[11]

Considering the clinical importance of LAEF and the increasing availability of this tool in echocardiography equipment, this parameter should be routinely reported.

3D echocardiographic assessment of left atrial volumes

In the last two decades, 3D echocardiography has become the modality of choice for volumetric quantification of cardiac chambers, with stronger correlation with CMR and less inter- and intraobserver variability. In a multicenter study with 92 patients with varying LA volumes, the agreement for the classification of enlarged LA using a cutoff point > 34 mL/m² showed a kappa coefficient of agreement of 0.88 between 3D echocardiography and CMR, compared to a kappa of 0.71 for the same analysis with 2D echocardiography and CMR.[12]

Some of the main advantages of this method include:

1. **High accuracy:** No geometric assumptions regarding LA shape, resulting in less underestimation compared to CMR
2. **Greater reproducibility:** Semi-automatic identification of cardiac borders, reducing foreshortened measurements.
3. **Acceptable temporal resolution:** Resolution > 20 volumes per second compared to CT and CMR
4. **Dynamic characterization of size and shape:** Continuous analysis throughout the cardiac cycle, allowing assessment of atrial functional phases.
5. **Single-beat acquisition:** Feasible analysis in patients who present frequent atrial or ventricular arrhythmias

Figure 6 shows the volumetric values and calculations performed using specific software for semi-automatic measurement.

Similar to 2D echocardiographic assessment of LA volumes, indexing 3D LA volumes to body surface area reduced sex differences. A small, yet significant increase in LA volume on 3D echocardiography has been observed with aging.

Currently, the main limitations of this analysis are temporal resolution, as well as the limited data regarding normal reference and prognostic values among diverse diseases.

Left atrial strain

Assessment of LA function by means of strain allows for more detailed analysis of each phase of atrial physiology. The ability to discriminate between passive and active movement, angle independence, reduced tethering effects, lower load dependence, and tracking of the movement of each segment of the atrial wall allow for a better understanding of atrial function.

LA strain is preferably measured by the speckle tracking method. For this purpose, the endocardial borders of the LA are manually or automatically traced on high-quality 2D images obtained at a frame rate between 50 and 90 frames/second. The need to acquire images in dedicated, non-shortened windows (as opposed to a conventional window optimized for the LV) to obtain LA strain measurements is a relatively recent concept and an essential parameter.

The European Society of Cardiovascular Imaging and the American Society of Echocardiography recommend using the LA strain value obtained from apical two- and four-chamber images, avoiding shortening, although strain analysis from the apical four-chamber window alone is also commonly performed and has proven accurate and reproducible. Dedicated software for LA strain analysis should be used, when available, to reduce variability and measurement errors.

As an additional recommendation, it is advised to obtain an image with the acquisition focused on the LA and a region of interest with a thickness of approximately 3 mm, due to the thin atrial wall.[1,13]

Two different temporal trigger approaches are available to quantify LA strain using the speckle tracking method. The first approach uses the beginning of the QRS complex

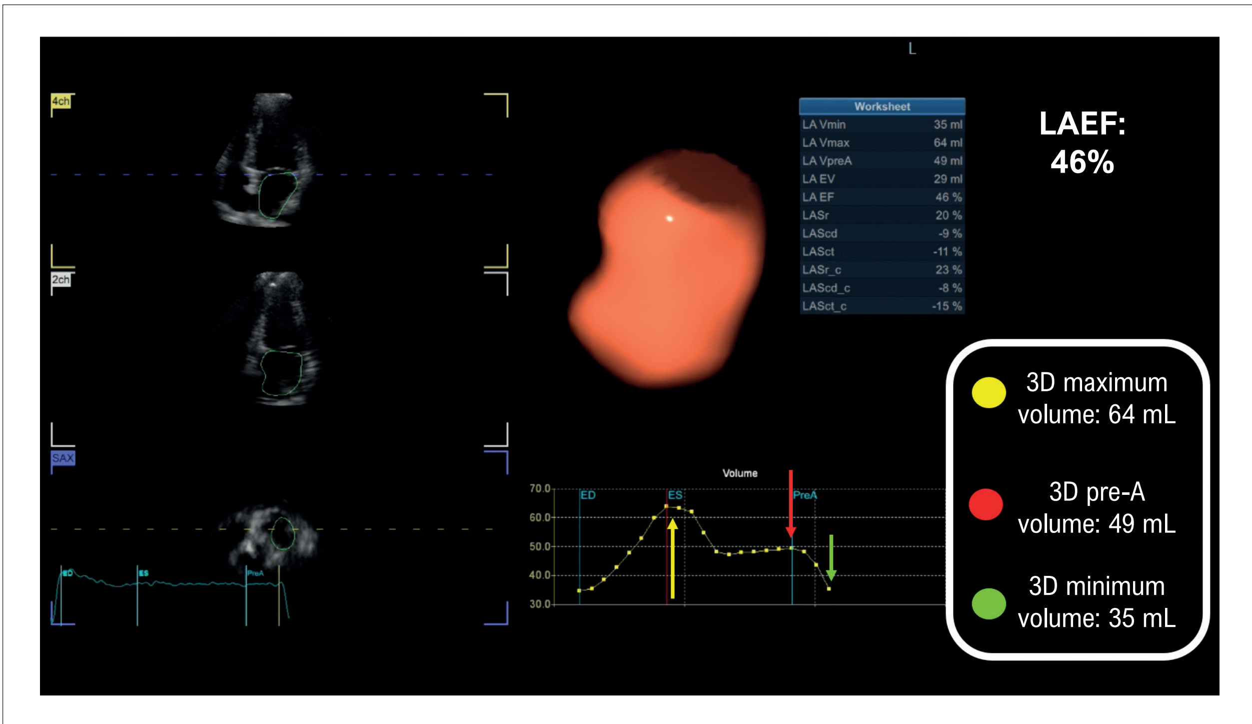


Figure 6 – *Semi-automatic 3D volumetric analysis of the LA (example of dedicated software). 3D: three-dimensional; LAEF: left atrial ejection fraction; pre-A: immediately before atrial contraction.*

derived from the electrocardiogram as a starting point (R-R trigger) and measures two key types of LA strain:

1. **Left atrial reservoir strain (LASr):** Analyzed at the end of LV systole (corresponding to aortic valve closure)
2. **Left atrial contraction strain (LASct):** Analyzed subsequently, corresponding to LA contraction.

The difference between LASr and LASct represents left atrial conduit strain (LAScd).

The second approach uses the P wave of the electrocardiogram as a starting point (P-P trigger), allowing the measurement of two deformations: the first descending, which corresponds to SAEct, and the second ascending, which corresponds to atrial relaxation and reservoir function.

Atrial parameters are smaller for the P-P interval-gated analysis compared to R-R gating. It is important to emphasize the impossibility of applying this analysis to patients with AF when P-P gating is used. Another point to highlight is that most studies published around the world have used R-R gating, making it the recommended method for measuring LA deformation.[13]

Figure 7 shows the main phases of LA deformation using R-R interval-gated analysis as a parameter.

Figure 8 shows both LA strain curve patterns, R-R or P-P interval, depending on the gating chosen.

Figure 9 illustrates the analysis of these three components of LA strain in a patient with hypertension, but without structural heart abnormalities.

The clinical importance of LASr has been reinforced by several studies demonstrating its independent prognostic value. The main studies conducted to date have validated this parameter as a prognostic marker in the following scenarios:[13]

- Acute myocardial infarction
- Chronic coronary syndrome
- Cardio-oncology
- ≥ moderate valvular disease (single or multiple valves)
- Dilated cardiomyopathy
- Acute or chronic HF
- Cardiac resynchronization therapy
- Athlete's heart
- Takotsubo syndrome

Normal LASr, LAScd, and LASct values are provided in Tables 4 and 5; however, the only recommended deformation parameter for LA function is global longitudinal deformation or LASr.

Segments adjacent to the mitral annulus, particularly in the inferior wall, normally exhibit higher strain values than those in the mid and superior (roof) segments of the LA. The lowest LA strain values are found in the LA roof, in the region of pulmonary vein insertion, where the heart is anchored to the mediastinum.

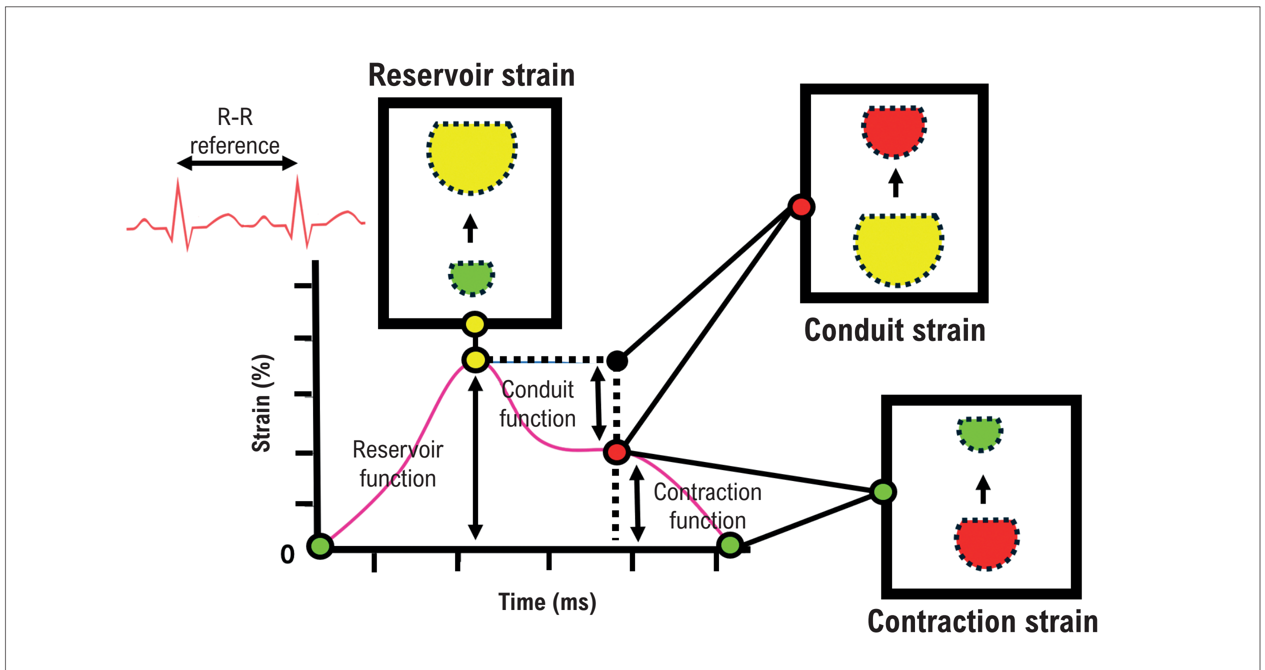


Figure 7 – *Left atrial strain curve (speckle tracking) with R-R gating: reservoir, conduit, and contraction strain.*

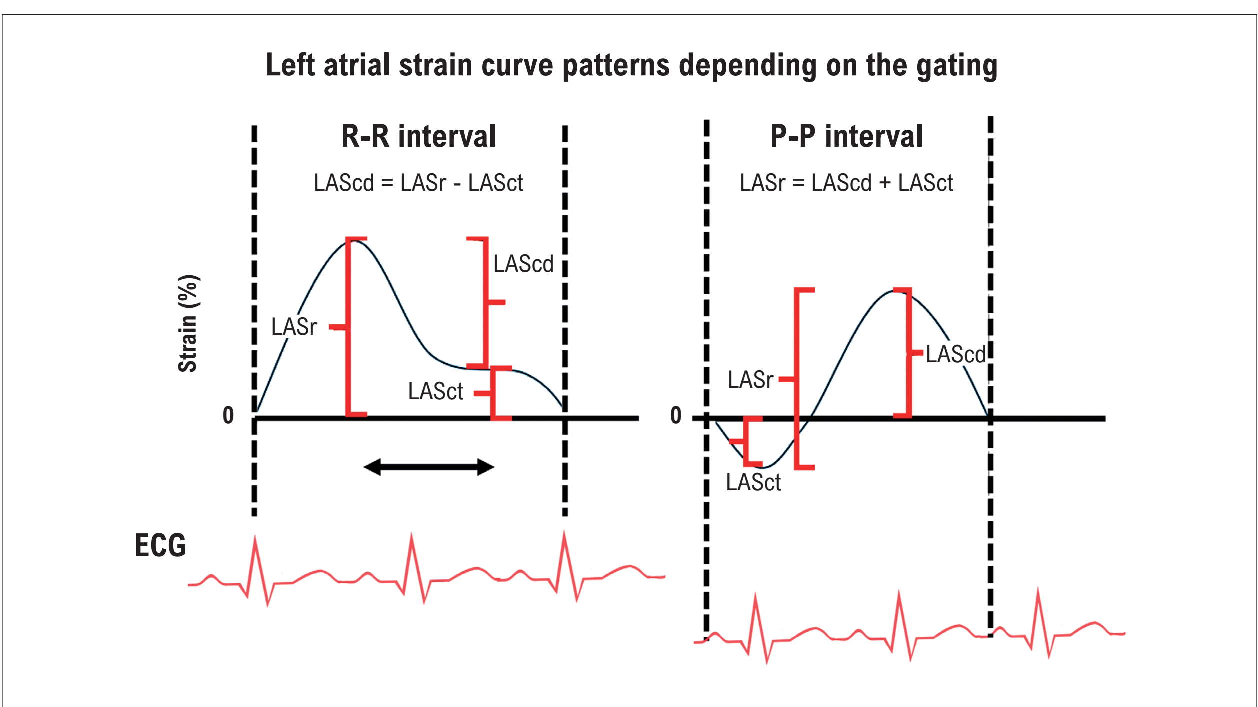


Figure 8 – *Two zero-reference approaches for left atrial strain assessment, and their respective curves. The strain values obtained with both techniques can be mathematically converted to one another. ECG: electrocardiogram; LAScd: left atrial conduit strain; LASct: left atrial contraction strain; LASr: left atrial reservoir strain.*

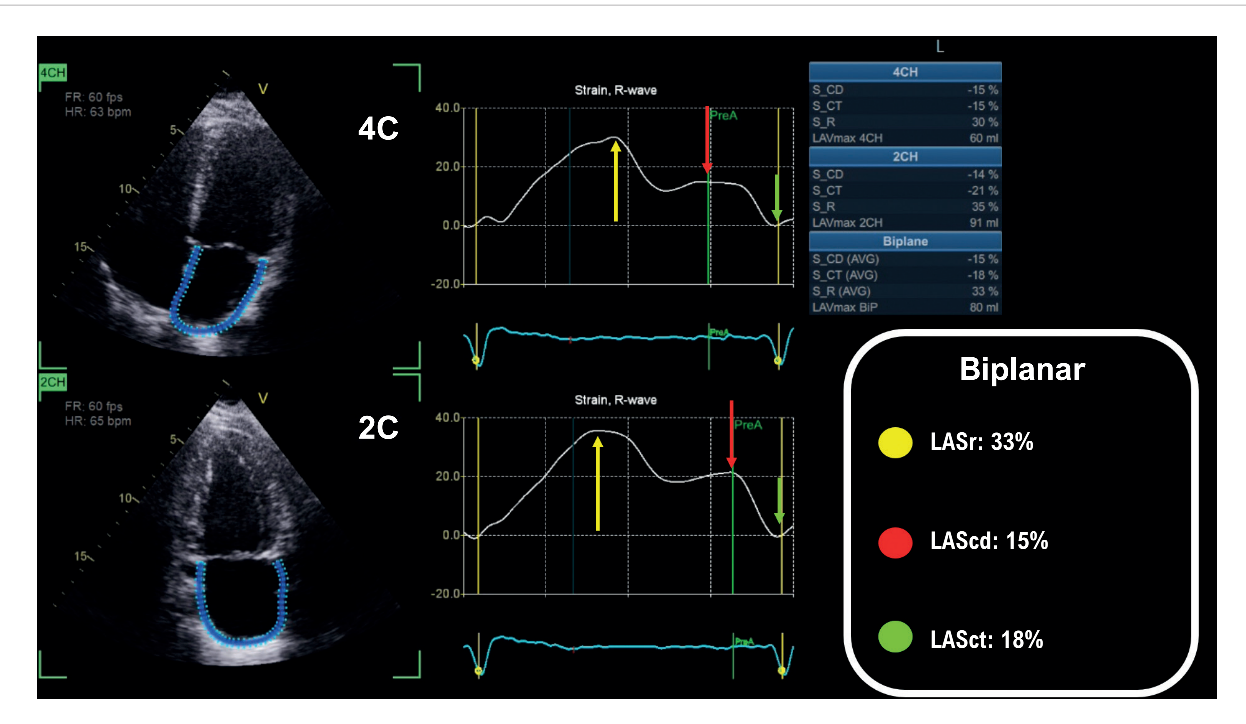


Figure 9 – *Analysis of left atrial strain in three phases (arrows: yellow = LASr; red = LAScd; green = LASct) in a patient with hypertension. Analysis was performed using dedicated software to measure left atrial longitudinal strain using automated left atrial endocardial tracking in apical two- and four-chamber views, following the recommendations of the European Association of Cardiovascular Imaging/American Society of Echocardiography/Industry Task Force to standardize deformation imaging.13 2C: two-chamber view; 4C: four-chamber view; LA: left atrium; LAScd: left atrial conduit strain; LASct: left atrial contraction strain; LASr: left atrial reservoir strain.*

Regional differences in LA strain may potentially be useful for assessing LA dyssynchrony, a parameter used as an indirect measure of heterogeneous LA fibrosis and dysfunction that can predict AF recurrence after radiofrequency ablation.

Mechanical dispersion of the LA or LA dyssynchrony, calculated as the standard deviation of the time to maximum strain of LA segments, was also evaluated for both reservoir and contractile strain, and both measures demonstrated value in predicting AF recurrence.[1,13]

The main limitations are related to the very thin LA walls, the interatrial septum which is often associated with hypermobility or aneurysm, the dependence on geometric assumptions in the regions of pulmonary vein and LA appendage insertion, in addition to the image field being presented in the most distal segment on echocardiographic analysis, and the fact that the LA is located in the most distant field during echocardiographic analysis.

The LA in assessment of diastolic function

Initially based on invasive hemodynamic studies, the assessment of LV stiffness and compliance constituted the initial pillars for identifying increased filling pressures and the development of LV diastology. In the case of patients with reduced ejection fraction, the elevation of filling pressures was more easily understood in light of systolic dysfunction. In patients with preserved ejection fraction, this interpretation became less straightforward, which prompted a deeper study of diastolic function.

With the incorporation of Doppler into echocardiography, there was a leap in quality in the non-invasive assessment of filling pressures, and studies emerged classifying another type of HF, diastolic HF, a term that would later be superseded by the preferred term heart failure with preserved left ventricular ejection fraction (HFpEF). The first guideline that guided the systematic assessment of LV diastole was published in 2009, already considering atrial variables for this assessment.

The LA and LV are structures arranged in series in the circulatory system, with the atrium serving the antechamber for the LV. Due to this close connection, LV diastolic function has a great influence on LA pressure and function. LA assessment, therefore, provides valuable information that can corroborate the identification and grading of LV diastolic dysfunction. This assessment was initially limited to analysis of transmitral flow and pulmonary venous flow. With the advent of new technologies, the identification of increased LA pressure has been made possible by more accurate variables: tissue Doppler of the mitral annulus during initial ventricular filling (e′ wave) and its relationship with the mitral E wave, with a mean E/e′ ratio greater than 14 being indicative of increased LA pressure. These variables, although important, may not be conclusive in some scenarios such as an E/e′ ratio between 8

and 14, mitral annulus calcification, atrial arrhythmias, and fusion of the E and A waves.

In 2025, the latest update of the guidelines for assessing LV diastolic function expanded the range of tools for this assessment. Among other variables, LASr less than or equal to 18% was included as another data point to be considered in this analysis. This addition was especially useful in the analysis of patients with preserved ejection fraction, a group in which strain alteration has high specificity for identifying increased LA pressure. With these additions and a new assessment flowchart, all patients previously classified as having indeterminate diastolic function (18.8% applying the 2016 criteria) were classified as having normal diastolic function or classified as having some degree of diastolic dysfunction, reducing the likelihood of inadequate quantification of diastolic dysfunction.[15]

In practice, this new guideline added parameters that increased the importance of the LA in diastology. The American Society of Echocardiography's Recommendations for the Evaluation of Left Ventricular Diastolic Function by Echocardiography and for HF With Preserved Ejection Fraction can be consulted for further guidance on diastolic assessment.[16]

Left atrial stiffness index

Impaired LA strain is closely related to the clinical presentation and diagnosis of HFpEF. When LA strain is used in conjunction with pulmonary artery occlusion pressure, invasively measured by catheterization, or with the E wave velocity/mitral e′ velocity ratio (E/e′), the LA stiffness index can be derived.[17,18]

The LA stiffness index can be estimated using the following two echocardiographic variables:

- **LASr:** peak longitudinal LA strain
- E/e′ ratio

The E/e′/LASr ratio is a relatively simple and non-invasive parameter to obtain and has shown good correlation with NT-proBNP and conventional echocardiographic diastolic parameters, including E/e′, indexed LA volume, and right ventricular systolic pressure. Kim et al. published an interesting retrospective study in the *Journal of the American College of Cardiology* in 2022, with 307 patients, demonstrating that the LA stiffness index showed stronger prognostic performance in predicting all-cause mortality and HF-related hospitalization than classic diastolic parameters, including E/e′, indexed LA volume, maximum tricuspid regurgitation velocity, and LASr during follow-up. An E/e′/LASr value > 0.26 had an area under the curve of 0.743 (95% confidence interval: 0.681 to 0.806; $p < 0.001$).

In that study, patients with invasively assessed LV end-diastolic pressure ≥ 16 mmHg and LV ejection fraction ≥ 50%, when presenting with an increased LA stiffness index (> 0.26), showed worse medium- and long-term prognosis compared to patients with the same characteristics and LA stiffness index ≤ 0.26, suggesting the potential use of this parameter as a prognostic biomarker based on echocardiographic imaging.[18]

New technologies (HeartModel)

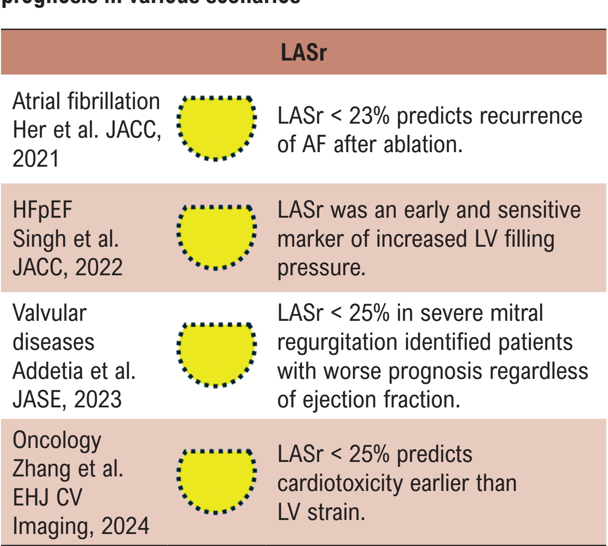
New technologies have been incorporated into echocardiographic analysis, allowing for greater reproducibility and speed in acquiring images and volumetric data. Volumetric assessments on 3D echocardiography, classically available on ultrasound devices, are presented as semi-automatic measurements, often requiring additional

Table 4 – Reference values for left atrial reservoir, conduit, and contraction strain[13,14]

Normal values Meta-analysis including 2,542 healthy individuals	
Phases	**Valores de referência**
LASr	**39%** (95% CI: 38%–41%) • Values < 23% associated with worse prognosis • Diastolic guidelines (values < 18% associated with increased LV filling pressures)
LAScd	**23%** (95% CI: 21%–25%)
LASct	**18%** (95% CI: 16%–19%)

CI: confidence interval; LAScd: left atrial conduit strain; LASct: left atrial contraction strain; LASr: left atrial reservoir strain; LV: left ventricle.

Table 5 – Main reference studies on LASr in relation to prognosis in various scenarios[13]



	LASr
Atrial fibrillation Her et al. JACC, 2021	LASr < 23% predicts recurrence of AF after ablation.
HFpEF Singh et al. JACC, 2022	LASr was an early and sensitive marker of increased LV filling pressure.
Valvular diseases Addetia et al. JASE, 2023	LASr < 25% in severe mitral regurgitation identified patients with worse prognosis regardless of ejection fraction.
Oncology Zhang et al. EHJ CV Imaging, 2024	LASr < 25% predicts cardiotoxicity earlier than LV strain.

HFpEF: heart failure with preserved left ventricular ejection fraction; LASr: left atrial reservoir strain; LV: left ventricle; AF: atrial fibrillation

adjustments for each of the analyzed cardiac segments, which would ultimately consume additional time that is often unavailable in clinical practice.

Companies such as Philips and General Electric have developed specific software for accurate and fully automatic measurements with single-click acquisition, allowing even echocardiography operators without extensive experience to easily perform this analysis.

In a feasibility and accuracy study with 159 patients, Tsang et al. demonstrated that the fully automatic software (HeartModel, Philips Healthcare) showed a strong correlation with the semi-automatic measurement with manual correction (r = 0.87 to 0.96). Additionally, the agreement between automated volumetric analysis and CMR was also significant (r = 0.84 to 0.95). The average acquisition and analysis time for LV and LA volumes was 37 seconds for the automatic HeartModel software, compared to 79 seconds for the same acquisition, but with minor manual adjustments made by the operator, and 212 seconds for 2D assessment by Simpson's method, with a final reduction of 82% in acquisition time.[19] An interesting finding of this analysis was that human post-processing changes did not lead to significant improvements compared to automatic volumetric analysis, using CMR as a reference.

Figure 10 illustrates acquisition using the Philips HeartModel A.I. software with automatic volumetric evaluation.

Figure 11 presents a step-by-step approach to structured left atrial (LA) analysis, encompassing the essential data that should be obtained from the echocardiographic study, as well as a summary table highlighting the strengths and limitations of the main parameters discussed throughout the text.

Conclusion

LA assessment has evolved from morphological analysis restricted to the anteroposterior diameter to an integrated functional approach that is capable of characterizing the three phases of the atrial cycle (reservoir, conduit, and contraction). This progression, which ranges from 2D volumetry to strain and atrial stiffness index, reflects a conceptual shift in recent literature. The LA is not a passive chamber, but rather an active determinant of cardiac performance and an independent prognostic marker in various clinical settings, such as AF, HF, and valvular heart disease.

The systematic incorporation of these parameters into routine echocardiography is, therefore, clinically justified. The inclusion of LA reservoir strain in the most recent diastolic function guideline exemplifies how this integration is already underway. As new technologies increase reproducibility and reduce acquisition time, LA functional analysis is likely to become consolidated as an essential component of echocardiographic reports, supporting more precise characterization and more informed clinical decision-making.

Author Contributions

Conception and design of the research, analysis and interpretation of the data and writing of the manuscript:

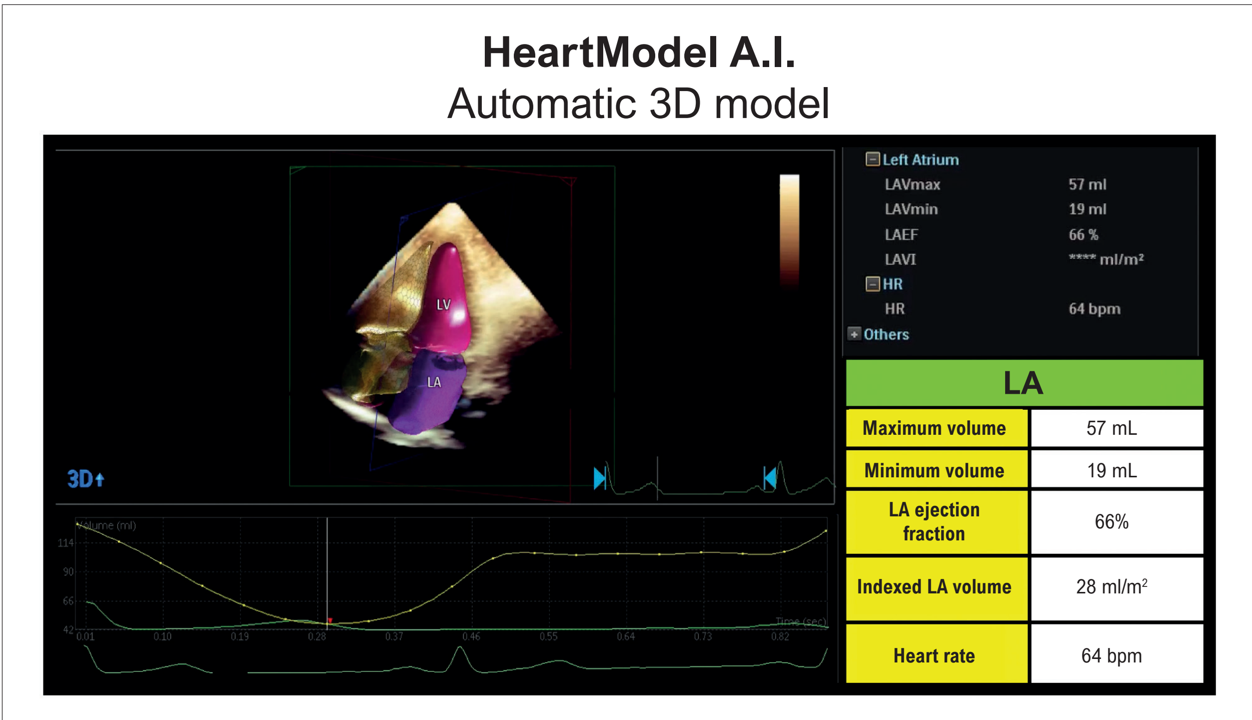


Figure 10 – *Automated 3D transthoracic quantification of left heart chambers using specific HeartModel A.I. software. LA: left atrium; 3D: three-dimensional.*

Take-home messages:

1. Linear dimensions: These dimensions should no longer be used, as they are not related to the actual size of the LA, especially if the LA is enlarged.

2. 2D LA volume assessment:

- **Strengths:**
  - Easy to perform
  - Widely available
  - Does not require dedicated software
  - Large body of data on normal values and data demonstrating prognostic value in various cardiac conditions
- **Weaknesses:**
  - Underestimates actual LA volume
  - Relies on geometric assumptions to calculate volume
  - Reasonable, but not optimal, interobserver variability and reproducibility

3. 3D LA volume assessment:

- **Strengths:**
  - Does not rely on geometric assumptions (more precise volumes)
  - Lower interobserver variability (ideal for serial measurements)
- **Weaknesses:**
  - Low spatial resolution
  - Requires a specific transducer for image acquisition, as well as software
  - Increased costs and limited supporting data on normal values and prognosis

4. LA reservoir strain:

- **Strengths:**
  - Uses conventional grayscale analysis
  - Easy to perform and highly reproducible
  - Demonstrated prognostic value in HFpEF (already incorporated into guidelines)
  - Increasingly available dedicated software packages
- **Weaknesses:**
  - Variability between providers has yet to be evaluated in large-scale studies
  - Prognostic value independent of LV longitudinal strain still needs to be established

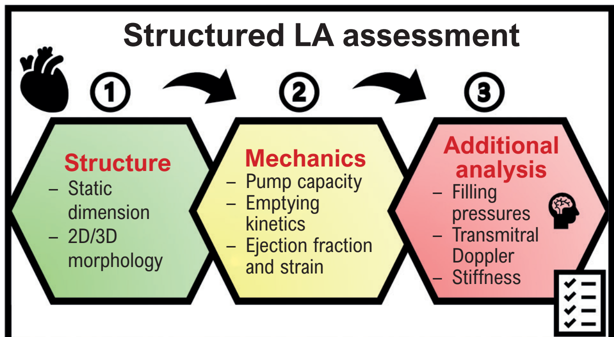


Figure 11 – *Top: Comparison of the pros and cons of different techniques: linear dimensions, LA volumes by the 2D biplane method, LA volumes by the 3D method, and LA reservoir strain. Bottom: Flowchart for a structured analysis of the left atrium using anatomical, functional, and hemodynamic data. These parameters should be reported at the end of the echocardiography report. 2D: two-dimensional; 3D: three-dimensional; LA: left atrium; HFpEF: heart failure with preserved left ventricular ejection fraction; LV: left ventricle. 2D: two-dimensional; 3D: three-dimensional; HFpEF: heart failure with preserved left ventricular ejection fraction; LA: left atrium; LV: left ventricle.*

Silva HAGP, Gomes HM; critical revision of the manuscript for intellectual content: Silva HAGP, Gomes HM, Souza AC.

Potential conflict of interest

No potential conflict of interest relevant to this article was reported.

Sources of funding

There were no external funding sources for this study.

Study association

This study is not associated with any thesis or dissertation work.

Ethics approval and consent to participate

This article does not contain any studies with human participants or animals performed by any of the authors. This article does not contain any studies with human participants or animals performed by any of the authors.

Use of Artificial Intelligence

The authors did not use any artificial intelligence tools in the development of this work.

Data Availability Statement

The underlying content of the research text is contained within the manuscript.

References

1. Thomas L, Muraru D, Popescu BA, Sitges M, Rosca M, Pedrizzetti G, et al. Evaluation of Left Atrial Size and Function: Relevance for Clinical Practice. J Am Soc Echocardiogr. 2020;33(8):934-952. doi: 10.1016/j.echo.2020.03.021.
2. Mangia M, D'Andrea E, Cecchetto A, Beccari R, Mele D, Nistri S. Current and Clinically Relevant Echocardiographic Parameters to Analyze Left Atrial Function. J Cardiovasc Dev Dis. 2024;11(8):241. doi: 10.3390/jcdd11080241.
3. Mitchell C, Rahko PS, Blauwet LA, Canaday B, Finstuen JA, Foster MC, et al. Guidelines for Performing a Comprehensive Transthoracic Echocardiographic Examination in Adults: Recommendations from the American Society of Echocardiography. J Am Soc Echocardiogr. 2019;32(1):1-64. doi: 10.1016/j.echo.2018.06.004.
4. Badano LP, Miglioranza MH, Mihăilă S, Peluso D, Xhaxho J, Marra MP, et al. Left Atrial Volumes and Function by Three-Dimensional Echocardiography: Reference Values, Accuracy, Reproducibility, and Comparison with Two-Dimensional Echocardiographic Measurements. Circ Cardiovasc Imaging. 2016;9(7):e004229. doi: 10.1161/CIRCIMAGING.115.004229.
5. Agner BF, Kühl JT, Linde JJ, Kofoed KF, Åkeson P, Rasmussen BV, et al. Assessment of Left Atrial Volume and Function in Patients with Permanent Atrial Fibrillation: Comparison of Cardiac Magnetic Resonance Imaging, 320-Slice Multi-Detector Computed Tomography, and Transthoracic Echocardiography. Eur Heart J Cardiovasc Imaging. 2014;15(5):532-40. doi: 10.1093/ehjci/jet239.
6. Lang RM, Badano LP, Mor-Avi V, Afilalo J, Armstrong A, Ernande L, et al. Recommendations for Cardiac Chamber Quantification by Echocardiography in Adults: An Update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. J Am Soc Echocardiogr. 2015;28(1):1-39.e14. doi: 10.1016/j.echo.2014.10.003.
7. Davis EF, Crousillat DR, He W, Andrews CT, Hung JW, Danik JS. Indexing Left Atrial Volumes: Alternative Indexing Methods Better Predict Outcomes in Overweight and Obese Populations. JACC Cardiovasc Imaging. 2022;15(6):989-97. doi: 10.1016/j.jcmg.2022.02.006.
8. Thomas L, Marwick TH, Popescu BA, Donal E, Badano LP. Left Atrial Structure and Function, and Left Ventricular Diastolic Dysfunction: JACC State-of-the-Art Review. J Am Coll Cardiol. 2019;73(15):1961-77. doi: 10.1016/j.jacc.2019.01.059.
9. Singh A, Singulane CC, Miyoshi T, Prado AD, Addetia K, Bellino M, et al. Normal Values of Left Atrial Size and Function and the Impact of Age: Results of the World Alliance Societies of Echocardiography Study. J Am Soc Echocardiogr. 2022;35(2):154-164.e3. doi: 10.1016/j.echo.2021.08.008.
10. Ferreira J, Gonçalves V, Marques-Alves P, Martins R, Monteiro S, Teixeira R, et al. Left Atrial Functional Assessment and Mortality in Patients with Severe Aortic Stenosis with Sinus Rhythm. Cardiovasc Ultrasound. 2021;19(1):1. doi: 10.1186/s12947-020-00231-0.
11. Inciardi RM, Giugliano RP, Claggett B, Gupta DK, Chandra A, Ruff CT, et al. Left Atrial Structure and Function and the Risk of Death or Heart Failure in Atrial Fibrillation. Eur J Heart Fail. 2019;21(12):1571-9. doi: 10.1002/ejhf.1606.
12. Mor-Avi V, Yodwut C, Jenkins C, Kühl H, Nesser HJ, Marwick TH, et al. Real-Time 3D Echocardiographic Quantification of Left Atrial Volume: Multicenter Study for Validation with CMR. JACC Cardiovasc Imaging. 2012;5(8):769-77. doi: 10.1016/j.jcmg.2012.05.011.
13. 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):335-68. doi: 10.1093/ehjci/jeag006.
14. Pathan F, D'Elia N, Nolan MT, Marwick TH, Negishi K. Normal Ranges of Left Atrial Strain by Speckle-Tracking Echocardiography: A Systematic Review and Meta-Analysis. J Am Soc Echocardiogr. 2017;30(1):59-70.e8. doi: 10.1016/j.echo.2016.09.007.
15. Hafez A, Farina JM, Ahmed S, Awad K, Pietri MP, Scalia IG, et al. Reclassifying Left Ventricular Diastolic Function with the 2025 American Society of Echocardiography Guideline versus the 2016 Algorithm. J Am Soc Echocardiogr. 2026:S0894-7317(26)00087-8. doi: 10.1016/j.echo.2026.02.013.
16. 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):537-69. doi: 10.1016/j.echo.2025.03.011.
17. Mathias IS, Rahi W, Ramos A, Na J, Angulo C, Rothstein P, et al. Validation of Noninvasive Left Atrial Stiffness Against Left Atrial Operating Chamber Stiffness by Cardiac Catheterization. JACC Cardiovasc Imaging. 2024;17(8):1000-2. doi: 10.1016/j.jcmg.2024.03.004.
18. Kim D, Seo JH, Choi KH, Lee SH, Choi JO, Jeon ES, et al. Prognostic Implications of Left Atrial Stiffness Index in Heart Failure Patients with Preserved Ejection Fraction. JACC Cardiovasc Imaging. 2023;16(4):435-45. doi: 10.1016/j.jcmg.2022.11.002.
19. Tsang W, Salgo IS, Medvedofsky D, Takeuchi M, Prater D, Weinert L, et al. Transthoracic 3D Echocardiographic Left Heart Chamber Quantification Using an Automated Adaptive Analytics Algorithm. JACC Cardiovasc Imaging. 2016;9(7):769-82. doi: 10.1016/j.jcmg.2015.12.020.

This is an open-access article distributed under the terms of the Creative Commons Attribution License