

Structural and Functional Measures of the Left Atrium

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INTRODUCTION

Quantification of Left Atrial (**LA**) structure serves as a cornerstone in the evaluation of diastolic function [1]; however, no measures of LA function have yet to be introduced to the clinic even though extensive research has propagated the diagnostic and prognostic potential of both 2-dimensional B-mode, tissue Doppler and strain parameters. The present chapter will be divided into a technical part, focusing on the merits, limitations and prospects of current and newer modalities for evaluating LA function, and a clinical part focusing on recent evidence supporting the application of LA functional measures.

ATRIAL PHASES

The LA serves three distinct phasic functions throughout the cardiac cycle; it works as a reservoir for the storage of blood from the pulmonary venous circuit during systole, as a conduit for the passage of blood to the Left Ventricle (**LV**), and it contributes to ventricular filling with an atrial contraction [2]. Often the reservoir and conduit phases are designated passive phases, and atrial contraction as the active phase. All phases are subject to age-related alterations and are modulated by both loading conditions and heart rate [2]. Furthermore, the phases are interdependent, which means that evaluation of one specific phase is seldom sufficient without consideration of the others [3]. This is illustrated by the findings made by Baltabeava et al [3] in a study of hypertensive patients: when faced with increased after load conditions (i.e. hypertension) a reduction in LA conduit function first appears and is met with a corollary increase in LA contraction to uphold an efficient LV stroke volume. The increase in LA contraction results in adequate filling of the LV, but also results in a reflux to the pulmonary veins, which subsequently increases LA preload, eventually causing LA dilatation. Two important points can be drawn from this example:

- 1) There is an intricate interplay between the different LA phases, but with a distinct timeline in how LA mechanical dysfunction develops. Thus, functional measures could have potential for detecting early stages of LA dysfunction, allowing for timely intervention before irreversible remodeling has occurred.
- 2) LA functional parameters are modified at early stages, before structural abnormalities such as LA dilatation appears.

The reservoir function is chiefly influenced by two overall conditions: (1) LV contraction, specifically the longitudinal displacement during systole, and (2) LA myocardial compliance [4]. This implies that besides conventional physiological parameters and atrial disease, a major contributor to impaired reservoir function is ischemic heart disease. Even at early stages of ischemic heart disease, LV longitudinal systolic function is known to be reduced [5]. Hence, as suggested by Morris et al [6], LV systolic function and history of ischemic heart disease should be considered when evaluating LA reservoir function.

The other passive phase, the conduit function, is largely governed by the same intrinsic (LA compliance) and extrinsic factors (LV displacement). However, this rather reflects ventricular relaxation, and early recognition of failure in ventricular relaxation, and the consequences thereof, could be done by considering LA mechanics as suggested in the example above. This could be relevant for the prevention of diastolic heart failure [4], now normally referred to as heart failure with preserved ejection fraction.

The atrial contraction is largely dependent on LV filling pressures, but to work as an efficient booster, the contraction also presumes synchronous electromechanical activity [4]. A prerequisite for adequate atrial pumping is therefore absence of structural abnormalities such as septal defects and scar tissue. LA contraction often increases as a compensatory response to failure of

the passive phases, but chronic compensatory response (as in the example above) results in LA dilatation, but if this dilatation progresses excessively, a critical threshold is reached where atrial contraction starts failing [2].

Ordinary physiological conditions may elicit specific changes in phasic patterns, which should be kept in mind when evaluating LA mechanics. Take age for example; throughout senescence there appears to be a progressive loss of passive atrial function, both reservoir and conduit function, however, an increase in atrial booster function also appears [7,8]. Similar alterations are seen in the presence of cardiovascular lifestyle diseases, including hypertension and diabetes [3,9]; however, studies have shown that such pathological patterns are subject to modification. This is seen in patients with hypertension, who experience a decline in passive atrial function, but also an increase in atrial booster function [3]. However, this relationship between hypertension and atrial function is modified by whether the patient is symptomatic or asymptomatic, by antihypertensive medication [10], and whether they experience diurnal variations in blood pressure including nocturnal dipping pattern [11,12]. This stresses the complexity of LA mechanics, and the cautious approach that one should take when interpreting LA mechanical dysfunction in such patients, but it also implies that there is a degree of reversibility and improvement in LA function that can be gained by medication for instance. Ablation studies have likewise revealed an improvement in atrial function after ablation procedures [13], suggesting that there is a potential for functional recovery in patients with LA mechanical dysfunction.

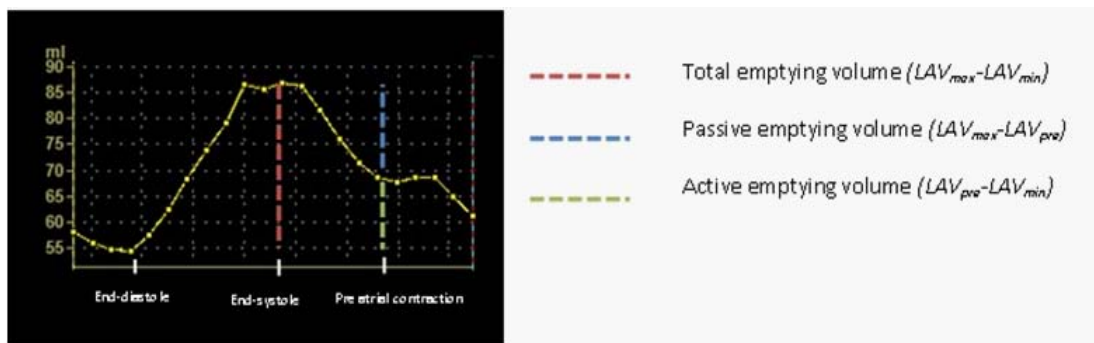
In summary, evaluation of LA mechanics can discover distinctive patterns of atrial dysfunction that are caused by specific diseases. It may furthermore provide insight as to the temporal failure of these atrial phasic functions, thereby providing information on whether the patient is at an early and reversible stage of their disease or not. Overall, assessment of LA function has the potential to detect patients at critical stages of diastolic dysfunction before the development of fulminant atrial cardiomyopathy, and thereby allow for early clinical intervention

LEFT ATRIAL VOLUMES COUPLED TO PHASIC FUNCTION

Currently, the only clinically applied measure of the LA is the maximal volume measured at LVend-systole (LAV_{max}). LA measures are clinically relevant not only for the evaluation of diastolic function, but also for the prediction of Atrial Fibrillation (**AF**), as will be discussed in depth later. Although the LAV_{max} has proven useful for predicting major cardiovascular events and incident AF [14,15], it is still largely determined by the atrial remodeling that occurs under prolonged exposure to augmented loading conditions [15]. This implies that the LAV_{max} is an unspecific marker, which is difficult to interpret clinically in patients with concomitant hypertension, valvular heart disease and otherwise elevated filling pressures. Furthermore changes in LA volume are considered a result of chronic overload, which is often preceded by changes in LA functional measures [3]. Accordingly, LA functional parameters have on several occasions proven useful for predicting outcome in patients without enlarged LA [16–18].

Other structural measures of the LA could be of interest [19,20], including the minimal volume obtained at the LVend-diastole (LAV_{min}) and the pre atrial contractile volume (LAV_{pre}). Together with LAV_{max} , these can be used to estimate the volume flow in the LA throughout the atrial phases (Figure 1), which allows for calculation of functional measures (Table 2). Functional derivatives include the LA Emptying Fraction (**LAEF**), which is the total volume expulsion in relation to the reservoir volume at LV end-systole (LAV_{max}). This measure is dependent on the absolute reservoir volume, but functionally is a measure of the volume that transits from the atrium to the LV, and thereby reflects the diastolic properties of the LA (Table 1). However, more phasic specific derivatives have also been proposed (Table 1) and include the LA passive Emptying Fraction (LApEF), LA active emptying fraction (LAaEF), and the LA expansion index (LAi). The LApEF reflects the conduit function as it represents the passive emptying volume in relation to the reservoir volume, thereby indicating the amount of volume exiting the LA immediately after mitral valve opening, at which time absolute reservoir volume in the LA (LAV_{max}) is present, and until just before atrial contraction occurs (LAV_{pre}). LAaEF on the other hand reflects the atrial contraction as it is calculated as the expulsion of volume from the LA at the onset of the p-wave (LAV_{pre}) until the minimal volume at end-diastole (LAV_{min}), in relation to the amount of blood in the LA before atrial contraction begins (LAV_{pre}).

Finally, the LAi represents the reservoir function exclusively, and is calculated as inflow of volume from end-diastole (LAV_{min}) until just before the opening of the mitral valve (end-systole, LAV_{max}) relative to the starting point being the end-diastolic volume.



Caption: The x-axis represents the timeline in the cardiac cycle, and the y-axis represents the volume change in the left atrium.

Figure 1: Left atrial volume curve.

Three points are used for the acquisition of the left atrial emptying volumes and calculation of the fractional changes:

- End-diastole, at the QRS-complex, just after mitral valve closure: acquiring the minimal atrial volume (LAV_{min})

- End-systole, at the end of the t-wave, just before mitral valve opening: acquiring the maximal atrial volume (LAV_{max})
- Pre atrial contraction, just at the onset of the p-wave: acquiring the LAV_{pre}

Table 1: Association between left atrial volumes and phasic function.

Left atrial measures	Index calculation	Reservoir	Conduit	Contraction
LAEF	$(LAV_{max} - LAV_{min}) / LAV_{max}$		X	X
LApEF	$(LAV_{max} - LAV_{pre}) / LAV_{max}$		X	
LAaEF	$(LAV_{pre} - LAV_{min}) / LAV_{pre}$			X
Lai	$(LAV_{max} - LAV_{min}) / LAV_{min}$	X		

LAEF: Left Atrium Emptying Fraction; **LApEF:** Left Atrial Passive Emptying Fraction; **LAaEF:** Left Atrial Active Emptying Fraction; **LAI:** Left Atrial Expansion Index; LAV_{max} : Left Atrial End-Systolic Volume; LAV_{min} : Left Atrial End-Diastolic Volume; LAV_{pre} : Left Atrial Volume at onset of the p-wave.

Although several studies have investigated the clinical implications of these volume indices, they have yet to be applied clinically. A central limitation has been the time-consuming process of performing LA planimetry several times during a single cardiac cycle to obtain these functional measures. Additionally, the low reproducibility related to non-automated planimetry, let alone sequential planimetry, further limits its clinical implementation. However, speckle tracking software for myocardial tracing now provides a continuous assessment of LA volumes curves during the entire cardiac cycle (Figure 1), thereby allowing for a quicker and more versatile calculation of volume-derived functional measures. This overcomes the time consuming process of performing multiple planimetrics, which is not clinically feasible. Volume curves allows for easy pin-pointing of cycle-specific LA volumes (Figure 1), and myocardial tracing has shown reliable reproducibility rates, which is expected to improve even further as automated software is being developed specifically for the LA. These benefits were highlighted in the study by Okamatsu et al [7], which revealed good correlation between speckle tracking derived volume curves and 2D planimetry for obtaining functional measures, with the main difference being the quicker (3 vs. 6 min, $p < 0.01$) and more reproducible process by LA myocardial tracing. Another notable limitation in the investigation of LA volumes has been the inherent uncertainty coupled to general 2D imaging acquisition, meaning that the measurements may not necessarily reflect true atrial structure [1]. However, this may be overcome by the more recent introduction of 3D echocardiographic imaging. Guidelines now state that volume acquisition for the LV should be performed with 3D analysis rather than 2D whenever possible [1], and the same could be expected for the LA once dedicated software and normative values have been validated and more widely established [1,21]. Such 3D tracing of the LA bypasses the geometric assumptions made by 2D imaging (Figure 2), and has been found to be more accurate when validated against Cardiac Magnetic Resonance Imaging (**CMR**) [22]. It also provides LA volume curves throughout the

entire cardiac cycles (Figure 1), allowing for functional derivatives of LA volumes. Additionally, it has been established that 3D LA volume is superior for longitudinal follow-up and sequential measurements in patients [23]. However, 3D imaging acquisition requires cooperation from the patient, reliable measures require high imaging quality, and overall has been deemed not yet ready for clinical recommendation [1].

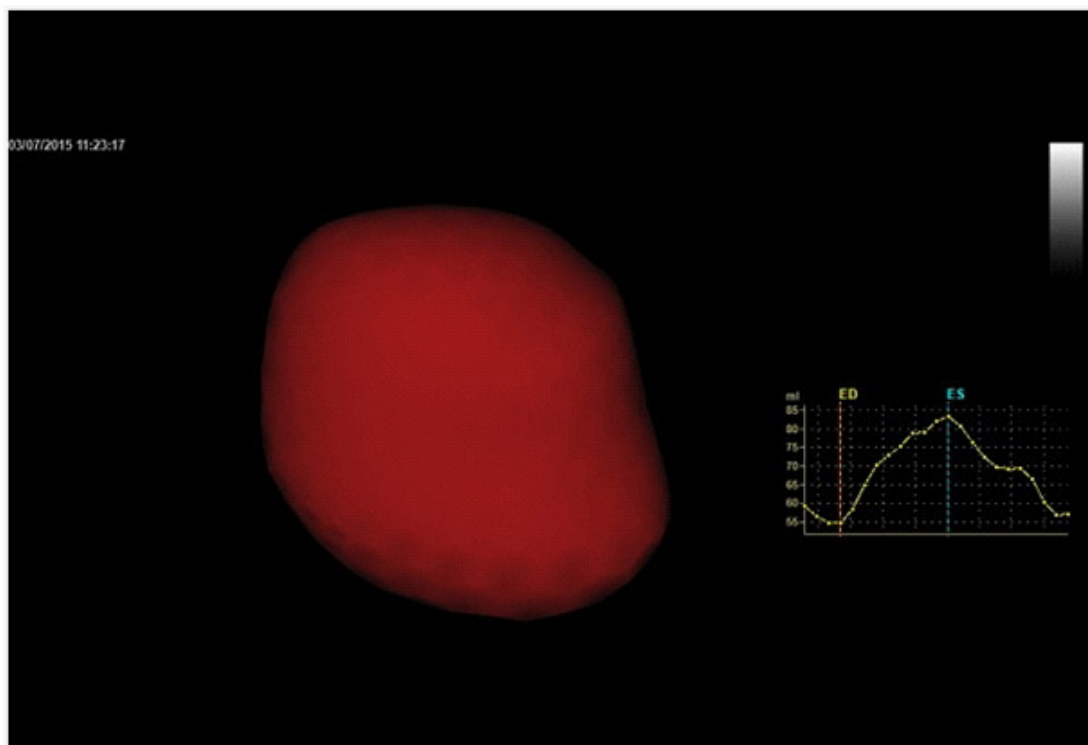


Figure 2: 3-Dimensional reconstruction of the left atrium and its corresponding volume curve.

LEFT ATRIAL STRAIN AND PHASIC FUNCTION

Just as for the assessment of ventricular strain, atrial strain can be evaluated both by tissue Doppler and speckle tracking. Speckle tracking has gained most focus recently, also for the evaluation of the LA, and will therefore be of focus here. Speckle tracking echocardiography is a software technique that uses an algorithm which identifies gray-scaled elements (speckles) within the myocardium and then continuously traces the movement of these speckles in relation to each other throughout the cardiac cycle. If the speckles move closer to each other (compression) you obtain a negative strain value, and conversely if the speckles move away from each other (elongation) a positive strain value are acquired. Atrial speckle tracking allows for the acquisition of LA peak reservoir strain (also denoted the positive atrial longitudinal strain; PALS) typically occurring at mitral valve opening (maximal elongation in systole), and strain value at the plateau

phase of the strain curve which corresponds to the deformation during atrial contraction (atrial longitudinal strain in late diastole; ALS_{late}). The difference between Peak Reservoir Strain (**PALS**) and plateau strain (ALS_{late}) corresponds to the conduit function (Figure 3 and Table 2). Besides the absolute strain values, strain rate values are also of interest, and particularly the late diastolic strain rate, representing the rate at which atrial contraction occurs, is worth mentioning. Atrial speckle tracking often provides LA volume curves, which can also be of value as mentioned in the previous section.

Caption: In this case, the whole LA in the apical 4chamber view is traced, and the white dotted line denotes the global longitudinal left atrial strain values. The reservoir function is presented by the white arrow, atrial contraction is the plateau phase value presented by the orange arrow, and the conduit function is the difference between these two distinctive peaks as shown by the blue arrow.

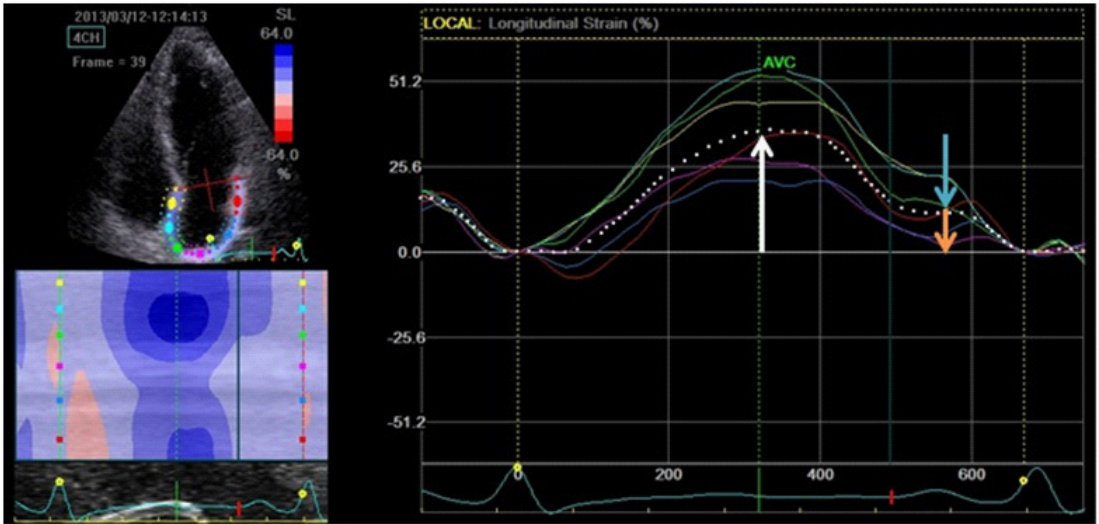


Figure 3: Left atrial speckle tracking and deformation curves.

Table 2: Left atrial strain measures and phasic function.

Left atrial measures	Index calculation	Reservoir	Conduit	Contraction
PALS		X		
ALS _{early}	PALS- ALS_{late}		X	
ALS_{late}				X
Late diastolic atrial strain rate				X

PALS: Peak Atrial Longitudinal Strain; **ALS_{early}:** Atrial Longitudinal Strain in Early Diastole; ALS_{late} : Atrial Longitudinal Strain in Late Diastole.

Atrial strain is a direct measure of myocardial tissue properties, as opposed to functional measures by LA volumes, which is rather an indirect assessment of LA function. Myocardial

speckle tracking has in many aspects proven superior to volume measurements for the LV, and has shown to add diagnostic and prognostic information beyond what can be obtained by LV volume measurements [24]. Consequently it is now being implemented in clinical guidelines [25]. The same could very well apply for the LA, although specific limitations and considerations adhere to the LA, which need to be clarified first. Atrial longitudinal speckle tracking suffers from the same limitations as conventional speckle tracking [26,27]. Additionally, no consensus has yet to be established for the proper tracking of the LA (Table 3). For instance some studies only trace the atrium in the 4 chamber view [18], others use biplane [12], and some use triplane assessments [28].

Another practical impediment that needs clarification is whether the roof of the atrium should be included, since it often visualizes the pulmonary venous structures, which do not contain any deformational properties of interest [4]

A specific limitation for the 4-chamber view is the interatrial septum, which is difficult to visualize by echocardiography and furthermore consist of fibro muscular tissue. As a consequence some studies have focused on the lateral wall of the LA and disregarded analysis of interatrial septal deformation [3]. Furthermore, studies have shown that the presence of atrial septal aneurysm itself influences the LA strain values, which should be considered in the speckle tracking analysis [29]. A similar problem exists for the 2-chamber view, in which the Left Atrial Appendage (**LAA**) often compromises the recognition of myocardial speckles and deformation analysis [4]. Finally, the ECG reference point is of particular importance, and different reference points have been utilized in different studies, which also demand a proper consensus as these presets greatly influences the absolute strain values [30].

Table 3: Limitations and considerations in left atrialspeckle tracking.

Intrinsic for all speckle tracking - Loading dependency - Angle dependency - Frame rate - Temporal and spatial resolution
Specific considerations for left atrial speckle tracking - Selection of uniplane, biplane or triplane analysis? - Inclusion of the roof of the atrium (pulmonary veins)? - 4-chamber view: inclusion and impact of interatrial septum, septal defects, and septal aneurysm? - 3-chamber view: exclusion of the wall of the ascending aorta - 2-chamber view: inclusion of anterior wall and left atrial appendage? - Selection of another ECG onset than that applied for ventricular speckle tracking?

Although the limitations seem excessive, extensive research has been performed, and normal reference values for the different atrial strain measures have even been proposed [6,31]. Additionally, many technical obstacles may be overcome by the development of automated software and by 3D imaging, in which atrial speckle tracking has shown promise [32]. Automated 3D speckle tracking would allow for highly reproducible tracking with valid assessment of LA volumes without geometric assumptions, and would also be able to track speckles in all

directions. This has been a widely debated issue for 2D speckle tracking since speckles may move in a direction out of the imaging plane and as such may not be tracked continuously and reliably. Finally, it would allow a comparative assessment with electromechanical and electro anatomical mapping, that could provide pathophysiological insight in for example AF [33].

Overall, atrial speckle tracking seems a promising tool of potential clinical value, but which still require some technical refinement and would benefit from a consensus statement on proper analysis as has been proposed for ventricular speckle tracking [26,34]. This could hopefully create a solid base, and trigger a more uniform technical approach on how to perform LA speckle tracking, which would make research studies more comparable in the future.

LEFT ATRIAL MECHANICAL DYSFUNCTION AND ATRIAL FIBRILLATION

The clinical potential of assessing LA mechanical dysfunction is far reaching and beyond the scope of this chapter, however, a central clinical problem has regarded AF, which will be described in detail. The ability to predict paroxysmal AF in high risk subjects and the recurrence of AF after cardioversion and catheter ablation could improve the clinical management of these patients.

Cryptogenic Stroke and Underlying Atrial Fibrillation

AF presents itself in various ways, which includes the clinically challenging asymptomatic paroxysmal AF. As AF is a known cause of thromboembolic strokes, it has been hypothesized that underlying AF may be the cause of a substantial proportion of seemingly cryptogenic ischemic strokes. This has been elaborated in a major randomized controlled trial, CRYSTAL-AF, which identified AF in a third of cryptogenic ischemic strokes by the use of implantable cardiac monitors [35]. Although the relation between newly detected AF and a recent cryptogenic ischemic stroke is hard to establish [36], patients with a stroke and AF should be started in anticoagulation treatment for secondary stroke prevention none the less given their inherently high CHA₂DS₂-VASc score. Cost-effectiveness-calculations have supported the use of implantable cardiac monitors for the detection of AF after stroke [37], however, this cost-benefit could be improved if a detailed echocardiographic risk-stratification were applied.

Accordingly, a lot of echocardiographic research has emanated from the point of improving risk stratification and the careful selection of high-risk subjects in need of prolonged rhythm monitoring. These include ancillary studies investigating differences in LA mechanics between patients with paroxysmal AF and healthy control subjects, in order to determine a potential marker that could be used as a predictor of AF in other patient groups (including ischemic stroke patients). Unfortunately, the studies so far have shown conflicting results, with some suggesting that a reduction in LA reservoir function could be a potent marker of paroxysmal AF [38], and others suggesting impaired LA booster pump function to do so [39]. Additionally, the application of implantable cardiac monitors is likely to detect subclinical events of AF as opposed to the

often more clinical events of paroxysmal AF that were used in these descriptive studies. This is supported by the fact that the TRENDS[40] and ASSERT[41] trials found that device-detected AF does not seem to convey the same thromboembolic risk as were to be expected by the CHADS2 score, supporting the notion that device-detected AF likely reflects a more subclinical and earlier stage of this arrhythmia. Keeping in line with this thought, echocardiographic measures should be able to predict such subclinical events, meaning that the measures proposed in the ancillary studies mentioned above may only have a propensity to predict paroxysmal AF at a fairly late stage, but not capable of predicting device-detected AF. Overall, findings made from these studies cannot be extrapolated and applied for prediction of device-detected AF, but could still serve as hypothesis generating observations for future prospective studies utilizing implantable device monitoring. When we look at the current evidence of echocardiographic predictors in populations with ischemic stroke patients, the same issue applies since only one study, the SURPRISE echo substudy, has investigated detailed echocardiographic risk markers in relation to device-detected AF [19].

A case-control study by Pagola et al [18] investigated the potential of atrial strain in patients with cryptogenic stroke, and found that reduced reservoir function by the LAV_{max} and PALS was associated with AF detected by 3-day Holter monitoring. However, PALS seemed superior to LAV_{max} in that it could predict AF in patients with structurally normal atria. It would have been interesting to see if other phasic functions by atrial deformation had incremental predictive value, unfortunately such measures were not reported. Furthermore, a study by Ersbøll et al has reported that the prognostic value of PALS is dependent on the Global Longitudinal Strain (**GLS**) of the ventricle and LA dilatation in patients with myocardial infarction [42], and it would have been interesting to see if this was also the case in the study by Pagola et al, since GLS is more easily obtained than LA strain. As a matter of fact a study investigating a large community-based cohort found that impaired GLS was predictive of new-onset AF, hypothesizing that this was due to a decrease in reservoir function [43]. As such, reservoir function may indeed be of value, particularly in the setting of predicting recurrence of AF following ablation (see next section), but its role in the follow-up after ischemic strokes remains to be seen.

In a study by Olsen et al [44] the LA reservoir function, determined by ventricular GLS (which is largely equal to LA reservoir strain) and LAV_{max} , did not prove to be predictive of AF in ischemic stroke patients. Instead LV speckle tracking revealed that LA contraction by late diastolic strain rate was predictive of AF. Unfortunately, Pagola et al did not investigate other deformation measures of phasic function, i.e. late diastolic strain rate that could confirm the clinical value of this measure. However, Stahrenberg et al made a similar finding in that a combined index value of reservoir and contractile function (LAV_{max}/a') was able to exclude patients from having AF [45]. Although measures of atrial booster function may have clinical value, these measures have yet to be reproduced in larger cohorts and by measures acquired by LA speckle tracking.

In a prospective study of cryptogenic ischemic stroke patients, Biering-Sørensen et al found that LAV_{min} and LAEF were predictive of device-detected AF, and to be superior to the LAV_{max} . Although Biering-Sørensen et al did not perform LA strain and deformation studies, applying LAV_{min} and LAEF seems clinically feasible as it only requires one additional measurement and demands less technical comprehension than LA speckle tracking. As noted earlier, device-detected AF may represent an arrhythmia at a more preclinical level, and the measures presented by Biering-Sørensen et al may therefore signify measures that could detect pre-clinical AF and early stages of atrial cardiomyopathy, whereas other measures of atrial deterioration may first appear later on. However, this remains to be examined by LA deformation in patients with prolonged implantable cardiac monitoring.

The findings made by Biering-Sørensen et al is in line with the study by Yoon et al, which evaluated LA volumes and reservoir strain in patients with paroxysmal AF in order to predict progression to persistent or permanent AF, and found LA reservoir strain to be an independent predictor of progression after multivariate adjustment[46], suggesting impairment of LA reservoir strain to represent a critical point of irreversible LA remodeling. This is supported by the study of Kuppahally et al[47], which evaluated differences in LA fibrosis and LA deformation in patients with paroxysmal AF compared to patients with persistent AF. LA fibrosis was evaluated by CMR-late gadolinium enhancement (CMR-LGE), and authors found that patients with persistent AF had more pronounced fibrosis. Interestingly was that in these patients the LAV_{max} and LAEF did not predict the amount of fibrosis, whereas PALS was a significant predictor. The amount of fibrosis is thought to uphold LA reentry circuits and thereby perpetuate AF. An ability of LA reservoir function to discriminate between fibrotic LA and non-fibrotic LA could prove useful for cardioversion and ablation (see next section), but also implies that patients with paroxysmal AF have managed to develop AF with a somewhat preserved reservoir function, hence failure of other phases may precede failure in reservoir function.

The evaluation of LA function after ischemic strokes have resulted in the proposition of various measures as potential predictors of AF, however, more extensive research including the whole spectrum of LA functional measures remains to be performed in studies with implantable devices. Additionally, other measures that have proven useful in ablation and cardioversion studies have yet to be examined in patients with ischemic strokes, and could add predictive information of relevance for the risk stratification of these patients.

Ablation and Recurrence of Atrial Fibrillation

Catheter ablation is an effective method for eliminating atrial arrhythmias, including AF. However, AF often recurs after ablation, and several attempts are often necessary for a successful elimination of this arrhythmia. Some patients unfortunately never experience improvement from ablation procedures as they have persistent recurrence of arrhythmias, and such patients should not have been subjected to this procedure to begin with, considering the procedure related risks.

The identification of patients who may be non-responsive to ablation therapy would reduce unnecessary procedures and hence reduce both procedure related costs and complications. Since all patients who undergo an ablation procedure will have an echocardiogram performed, a detailed analysis of LA mechanics could help identify patients who may be refractory to treatment. The utility of LA strain is, however, not restricted to predict AF recurrence, but also to guide the ablation approach. A study by Ipek et al found that not only did LA functional measures predict AF recurrence, but it had an additive predictive value in patients in whom linear lesions had been performed as part of the ablation technique [48]. The conclusion by Ipek et al was that in a patient with reduced reservoir function, performing linear lesions as part of the technique should be avoided since this could potentially worsen the outcome. Of course this requires further studies, but the concept of directing the procedure based on echocardiographic measures is intriguing.

A vast amount of LA functional studies have been conducted for the prediction of AF recurrence. An important point to keep in mind is that these patients can present in AF rhythm during their echocardiogram as opposed to cryptogenic stroke patients, who by definition are in sinus rhythm. Hence, in these patients with AF rhythm there is no LA contraction phase, and studies have therefore focused on other parameters for prediction of recurrence, including LA dyssynchrony. The rationale for investigating LA dyssynchrony is that there is a heterogeneous pattern in LA fibrosis and dysfunction, which can be detected by this more regional analysis rather than by looking at global LA strain values. Interatrial dyssynchrony defined both as maximal time to peak delay to the opposing atrial wall [49] and as mechanical dispersion [50] (standard deviation in time to peak), has shown promise for the prediction of recurrence after ablation. Although regional heterogeneity could play a vital role in ablation, global measures of the LA reservoir strain has been more extensively studied and several studies suggest that it may be a superior predictor of successful ablation outcome [51–56]. CMR-LGE imaging studies and histological studies have shown that recurrence of arrhythmias following ablation is directly related to the amount of fibrosis before ablation [57]. Since reservoir function by LA speckle tracking has shown a linearly inverse relationship to CMR-LGE detected fibrosis [47], reservoir function may very well be a strong predictor of successful outcome. Mahnkopf et al recently devised the Utah classification to predict successful ablation, in which atrial strain plays an integral part of the prediction model [58], bringing atrial strain one step closer to clinical implementation. Thus, in a patient with a critically low reservoir function, fibrosis is to be expected, and one should carefully consider the successful outcome that can be expected in such a patient, and perhaps abstain from the procedure altogether.

Another intriguing approach is to look at the improvement in reservoir function following ablation, which could be of value for the early recognition of patients who experience a recurrence of AF and in whom a second ablation is considered [56]. Finally, regional assessment of reservoir function could prove valuable as an indirect measure of post-ablation fibrosis. In the focal areas where the ablation procedure has been performed fibrosis is to be expected [59], and insufficient fibrosis (and thereby higher reservoir strain) could indicate incomplete ablation and predict AF

recurrence. Although regional disparities in reservoir function have incidentally been found to relate to AF recurrence following ablation [60], echocardiographic studies has not been conducted to test this hypothesis yet.

In summary, LA mechanics could very well play a vital role for the prediction of AF recurrence following ablation, and specifically the LA reservoir function relates directly to the amount of fibrosis in the atrium as validated with CMR-LGE, and this measure could be expected to be implemented in the future. The value of regional LA function still remains to be elucidated, and so does the ability of LA measures to guide ablation technique which requires further studies.

CONCLUSION

Evaluation of LA mechanics can be done in several ways, and particularly LA speckle tracking which allows for both volume acquisition and strain measures has the potential to become an integral part of echocardiography in the future. However, guidelines and position papers on how to properly perform LA speckle tracking are lacking, and are essential for the interpretation of research studies and before clinical implementation can be considered. As such, measures of the LA still rely on volume acquisition. However, increasing evidence suggests volume-derived functional measures to be superior to the LAV_{max} , and should be considered implemented clinically to complement the LAV_{max} .

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