Electrocardiographic Predictors of Atrial Fibrillation

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Abstract:

Atrial fibrillation (AF) is the most common sustained cardiac arrhythmia encountered in clinical practice and is associated with increased risk of stroke, heart failure, and all-cause mortality. Early identification of individuals at risk is crucial for timely intervention and prevention of complications. Electrocardiography (ECG), being a widely available, non-invasive, and cost-effective tool, provides valuable markers that may predict the development of AF. Several ECG parameters such as P-wave duration, dispersion, morphology, and axis deviation, as well as PR interval variability, atrial premature complexes, and abnormalities in interatrial conduction, have been linked to AF risk. Understanding these electrocardiographic predictors not only enhances risk stratification but also contributes to improved patient management, surveillance strategies, and the design of preventive therapies.

Keywords: Atrial fibrillation, Electrocardiography (ECG), P-wave dispersion, Interatrial block, PR interval, Atrial conduction abnormalities, Arrhythmia prediction, Cardiac electrophysiology.

Introduction:

Depending on age and location, the estimated prevalence of AF in the general adult population varies between 1 and 4%. An estimated 33 million persons worldwide have AF, which accounts for 0.5–4% of different populations. (1) According to the Global Burden of Disease (GBD) study, the prevalence of AF has rapidly increased globally, primarily due to aging populations, Increased prevalence of cardiovascular risk factors, such as diabetes, obesity, hypertension, and chronic renal disease. Over the past 20 years, the number of AF sufferers worldwide has more than doubled.

The structural and functional alterations in the atria that provide the foundation for the onset and maintenance of atrial fibrillation are referred to as atrial remodeling. comprises: structural: fibrosis and enlargement (dilatation). Functional: Modified electrical conductivity, reduced compliance, impaired atrial contraction, and AF patient management. (2) One of the main objectives in anticipating and avoiding atrial fibrillation is to identify left atrial (LA) functional remodeling at an incipient (early) stage prior to morphological changes. (3) By customizing anticoagulation, rhythm control, and lifestyle/pharmacologic therapies to each patient's risk and atrial substrate state, the integration of echocardiographic data into AF risk prediction allows for genuinely individualized care.

Left Atrial Size in AF

Elevated Left Atrium (LA) dimensions are directly linked to the incidence of AF and are linked to poor cardiac outcomes (4).

The LA's dimensions are significant indicators of structural change that could also subtly reveal details about the arrhythmogenic substrate. Since atrial fibrosis causes LA enlargement, its diameter, area, and volume were suggested as the first anatomical changes before AF appeared. As a result, LA enlargement aids in measuring LA anatomical remodeling. The development and recurrence of AF are predicted by the LA's dimensions.(5)

Regardless of whether the AF was paroxysmal or non-paroxysmal, anteroposterior LA diameter more than 50 mm was a predictive predictor of recurrences following the first AF ablation (6).

Additionally, Tops et al. (7) found that a LA AP diameter of less than 45 mm, which is linked to reversal remodeling following radiofrequency catheter ablation, is indicative of a favorable long-term prognosis.

Because LA remodeling is asymmetrical, volumetric measurement is more accurate in evaluating LA enlargement than linear or area assessments (8). The volume should be measured in dedicated views using the area-length method or modified biplane disk summation, avoiding foreshortening of the LA long axis. Measurements should not include the LA appendage or pulmonary veins. TTE makes it possible to measure every LA volume:

In left ventricular end-systole, the maximal LA volume is measured immediately prior to the mitral valve opening, while in end-diastole, the minimal LA volume is taken at the mitral valve closure(3).

The pre-atrial contraction volume, which is assessed at the beginning of the P-wave on the ECG, makes up the LA passive volume. The technique necessitates specific viewpoints and makes geometric assumptions about the spatial geometry of LA since it relies on the proper placement and angulation of image planes.

Planimetry in the apical 4- and 2-chamber view can be used to assess the left atrium area. Less than 20 cm2 is the typical reported number for the LA area. Volumes are simple to compute, and because of the extensive research on prognosis, they are more significant than area reporting. (9) More than 50% of patients may be incorrectly diagnosed based solely on LA diameters and area measures, which do not account for the presence and severity of LA dilatation. (10) Regardless of gender, an increased LA indexed volume is defined as greater than 34 mL/m2. For predicting AF recurrences, a 2D-E LAindexed volume of 34 mL/m2 had a 70% sensitivity and a 91% specificity. Increased LA volumes are independently predictive of AF onset (12), recurrences following AF ablations (13), or progression to permanent AF types (14) according to multiple meta-analyses.

Left Atrial Function in AF

The more subtle functional modifications of the LA may take place before the above-mentioned large physical changes. During the cardiac cycle, the LA performs three distinct roles: (1) it contracts as a "booster pump" during late left ventricular diastole, (2) it operates as a "reservoir" during systole, and (3) it functions as a "conduit" during early ventricular diastole. (15) LA passive volumes include the pre-atrial contraction volume, which is assessed at the beginning of the P-wave; the minimal LA volume, which is measured at the end diastole when the mitral valve closes; and the maximal LA volume, which is measured just prior to the mitral valve opening in the end systole. LA reservoir volume, also known as LA filling volume, LA conduit volume, also known as LA passive emptying volume, and LA contractile volume are the three LA active volumes. New echocardiographic methods or volumetric evaluations may be used to compute the functions. There are currently no established routine indications for measurements. (16) Several cardiovascular disorders, with a focus on AF, have been linked to changes in LA phasic functions. (17) If we take into account manual delineations of the LA myocardium, evaluating LA volumes entails a laborious procedure with poor reproducibility. showed a strong relationship between the speckle-tracking derived volumes of the identical images and the 2D-E manually traced LA volumes measurements. (18) In the general population, functional measurements of the LA are reliable indicators of AF. After assessing nearly two thousand participants over an 11-year follow-up period, the Copenhagen City Heart Study came to the conclusion that, in addition to LA volumes (maximum and minimum), the LA ejection fraction—which is determined by dividing the difference between LA maximum and LA minimum volumes by LA maximum volume—was also an independent, albeit weak, predictor of the occurrence of AF. (19).

After adjusting for LA size, the Left Atrial Function Index (LAFI) is a composite echocardiographic measure that measures both left ventricular (LV) stroke volume and LA mechanical function. LAFI combines Indexed LA end systolic volume (LAESVI), LVOT velocity–time integral (LVOT VTI), which serves as a stand-in for stroke volume, and LA emptying fraction (LAEF), which represents the left atrium's reservoir function. The established formula for calculating the left atrial function index is LAFI=LAEF × LVOT–VTI/LAESVI.

The left atrial maximal (LAESVi) and minimal (LAEDVi) indexed volumes are measured and the previously published formula, LAEF ([LAESVi − LAEDVi]/LAESVi) × 100, is used to get the LA emptying fraction (LAEF). (20)

LAFI has become a promising predictor of AF, especially for determining the risk of stroke, recurrence following ablation, and AF in patients. Even in cases where there was no substantial increase in LA volume, patients with chronic AF had considerably lower LAFI than matched controls. LAFI remained low in those who relapsed after successful cardioversion, whereas it improved in those who maintained sinus rhythm. (15)

In the Framingham Offspring Study, a community-based study of middle-aged adults: The probability of getting AF was 3.8 times higher for participants in the lowest LAFI quartile than for those in the highest quartile. Nevertheless, LAFI did not considerably enhance overall AF prediction performance when incorporated into conventional risk models. (21)

168 AF patients following catheter ablation were assessed in a prospective study. Reduced A higher recurrence of AF after ablation is linked to a lower pre-ablation LAFI. When compared to the CHADS-2score, LAFI also demonstrated a better capacity to distinguish AF recurrence, particularly in patients with persistent AF. (22)

Left Atrial Evaluation Using Pulsed Wave Doppler Echocardiography

Mitral inflow pattern

The loss of atrial contraction in AF is a defining feature of LA dysfunction; the A wave vanishes but resurfaces when SR is restored. Since complete recovery of mechanical activity does not happen right away following successful SR restoration, the A wave velocity is assessed as a stand-in for the LA contraction function. As long as LA systolic function does not return right away, the A wave velocity following cardioversion to SR from AF is modest. LA startling is the term used to describe this phenomenon. Depending on how long AF lasts, left atrium stunning can last anywhere from 24 hours for the paroxysmal pattern to up to 3 weeks following cardioversion. **(23)**

Pulmonary Venous Flow Assessment

By inserting the sample volume 1 to 2 cm into the pulmonary vein orifice, the pulsed-wave Doppler PVF velocity pattern can be captured. The pulmonary venous first systolic wave (S1), pulmonary venous second systolic wave (S2), pulmonary venous early diastolic wave (D), and pulmonary venous atrial reversed flow wave (AR) typically comprise the tri- or quadriphasic pattern of the normal PVF (24)

If LA is dilated or pressure is raised, the loss of atrial contraction (i.e., atrial systole) in AF results in: Absent or muted AR wave S/D ratio reversal, Reduced systolic blood pressure even in sinus rhythm Doppler echocardiography measures pulmonary venous flow, which is indicated by a lower systolic peak velocity, a reduced velocity-time integral, and a reduced systolic fraction. This is linked to left atrial dysfunction, which increases the risk of thrombus formation and recurrent atrial fibrillation in patients once sinus rhythm is restored. (25)

Data on the additive prognostic effect of pulmonary venous velocities are presented by Buffle et al., 26. The best indicator of readmissions for heart failure, as measured, was the S/D ratio, which is the ratio of peak systolic and diastolic velocities. Growing disparity between the Ar and mitral duration Additionally, a velocity was linked to readmissions for heart failure.

The pulmonary venous AR duration may surpass the mitral A wave duration when the LV end-diastolic pressure surpasses 15 mm Hg, resulting in a positive AR-A duration differential. elevated AR As a stand-in for raised LV and LA pressures, a duration difference probably indicates a higher risk of AF. Normal: AR duration is either the same as or less than the duration of mitral A (27).

A prospective study of 65 patients with WPW and AVRT was conducted. During EPS, 29 (44.6%) patients experienced AF that lasted for at least 30 seconds. In patients with WPW syndrome and AVRT, there was an increased risk of atrial fibrillation (AF) when there was a decrease in the right upper pulmonary vein (RUPV) systolic velocity ($P < 0.005$) and systolic to diastolic velocity ratio ($P < 0.005$), an increase in the atrial reversal velocity ($P < 0.05$) of RUPV flow, and a difference between the duration of RUPV atrial reversal flow and the A wave of the mitral profile ($P < 0.05$). In those patients, systolic and atrial reversal velocities were found to be independent predictors of atrial fibrillation. (28).

Left Atrium Appendage (LAA) Flow Velocity

A meta-analysis of 16 trials including 5,006 patients discovered that a higher risk of AF recurrence following catheter ablation was linked to a lower LAA flow velocity. Every 1 cm/s increase in LAA flow velocity was linked to a 3% reduction in AF recurrence risk The subgroup analysis demonstrated that neither the type of AF nor the ablation technique had a significant impact on the relationship between LAAFV and AF recurrence following catheter ablation. **(29)**

LA Function Evaluation with Tissue Imaging Echocardiography

Aging is one among the many prevalent risk factors for diastolic dysfunction and AF. The majority of diastolic parameters are known to change with age: the E and E' wave velocities drop, but the A wave, the E wave deceleration time, and the E/E' ratio increase. (Caballero and others, 2020) Following catheter ablation, the E/E' ratio is linked to a higher risk of late AF recurrence and correlates with LA pressures. (30)

The time interval between the beginning of the P wave in lead II and the peak of the A wave on the tissue Doppler tracing from the lateral LA wall is known as the PA-TDI Interval (Atrial Electromechanical Delay). Following radiofrequency ablation, left atrial asynchrony was shown to be an independent predictor of AF recurrence (31).

Numerous studies have shown how useful the PA-TDI length is in predicting the beginning of new-onset AF. Furthermore, a number of studies have shown how the length of

A-TDI affects the prognosis of postoperative AF and AF recurrence following cardioversion or ablation. **(32, 33)**

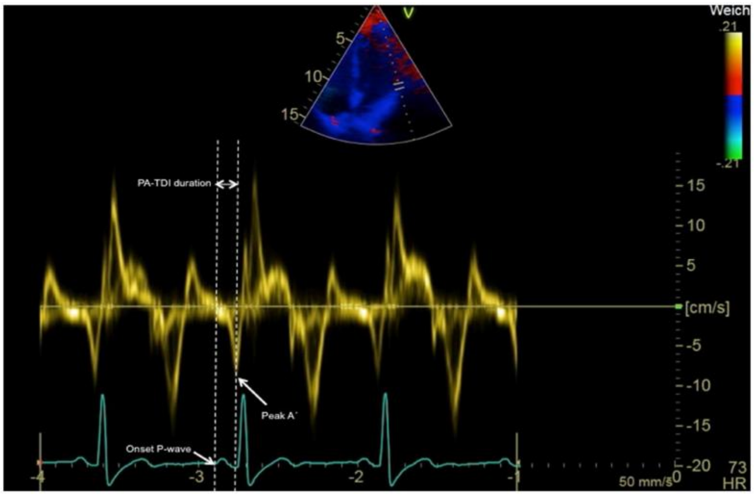

Figure (1): The Measurement of PA-TDI Interval **(34)**

Inter- and Intra-atrial Electromechanical Delay (EMD)

The term "interatrial mechanical delay" describes the interval of time between the left and right atria's mechanical activation. The most popular methods for evaluating it are strain imaging using echocardiography or tissue Doppler imaging (TDI). Using TDI, measure the interval between the ECG's P-wave and the atrial contraction wave (A′) at the tricuspid and lateral mitral annuli. But The time difference between the PA-TDI timings of the lateral mitral annulus and the septum is known as intra-atrial EMD. (35)

Including IAMD in routine echocardiograms could improve AF prevention tactics, especially for high-risk individuals. P-wave dispersion, left atrial size, and oxygen desaturation severity—factors known to predispose to atrial fibrillation—all positively linked with the markedly elevated interatrial and intraatrial EMD in patients with moderate-to-severe OSA. (36)

There was a weak connection between TDI and EPS (correlation coefficient $r = 0.308$, $p = 0.002$) in an investigation of 101 patients who had both invasive electrophysiological measures and TDI evaluations. A non-invasive method of estimating these delays is DI, which has a strong correlation with invasive electrophysiological data, especially for intra-atrial conduction. (37)

Avci et al. (38) demonstrated that in patients with Grade I and II HT who have no history of AF and whose condition has lasted no more than six months, prolonged PLA and intra- and inter-atrial delays may be significant indicators of early atrial structural and electromechanical alterations. The LV Mass index may be connected to the extension of these parameters.

P-wave dispersion and interatrial EMD were significantly higher in children with acute rheumatic fever than in matched controls ($p < 0.001$). A substrate for arrhythmogenesis was suggested by the correlation between the prolongation and left atrial hypertrophy. (39)

Interatrial block frequently indicates severe LA electromechanical dysfunction, with delays of around 127 ± 33 ms, and dyssynchrony raising the likelihood of AF. During a 16-month study, AF developed in 52% of individuals with interatrial block (IAB) and 18% of those without. Even in sinus rhythm, IAB was associated with thromboembolic risk (stroke, for example).

Atrial conduction heterogeneity is indicated by prolonged intra- and inter-atrial conduction times. For measuring atrial EMD, invasive electrophysiological tests are the gold standard. Thus, using tissue Doppler echocardiography, a noninvasive technique, the measurability of atrial EMD was assessed. In a study by Deniz et al. (37), the results of tissue Doppler examination and electrophysiological studies were compared in order to measure atrial conduction time in patients with PAF. They discovered a correlation between intra-left atrial EMD as determined by ECG and left intra-left atrial conduction time.

Following CRYOBALOON ablation, the determinants of AF recurrence were examined. It has been observed that intra-left atrial EMD is an independent predictor of recurrent atrial fibrillation. (40)

LA Function Evaluation with Speckle Tracking Echocardiography

Speckle Tracking Echocardiography STE is a type of echocardiography that records, frame by frame, the natural acoustic markers (or "speckles") in the heart tissue. It offers a quantitative evaluation of cardiac deformation (strain) that is independent of angle. Atrial longitudinal strain, also known as atrial strain, is the fractional change in the length of the total atrial myocardium contour in the tangential direction (16).

According to atrial physiology, the LA longitudinal strain curve is divided into three phases: phase of contraction, conduit, and reservoir While LA strain in the contraction phase (LAS-ct) or peak atrial contraction strain (PACS) corresponds to LA systole with active myocardial shortening that generates the atrial contribution to ventricular filling, LA strain in the reservoir phase (LAS-r) corresponds to LA early diastole (peak atrial longitudinal strain, or PALS); and LA strain in the conduit phase (LAS-cd) corresponds to LA mid-diastolic emptying with its passive shortenings. (41)

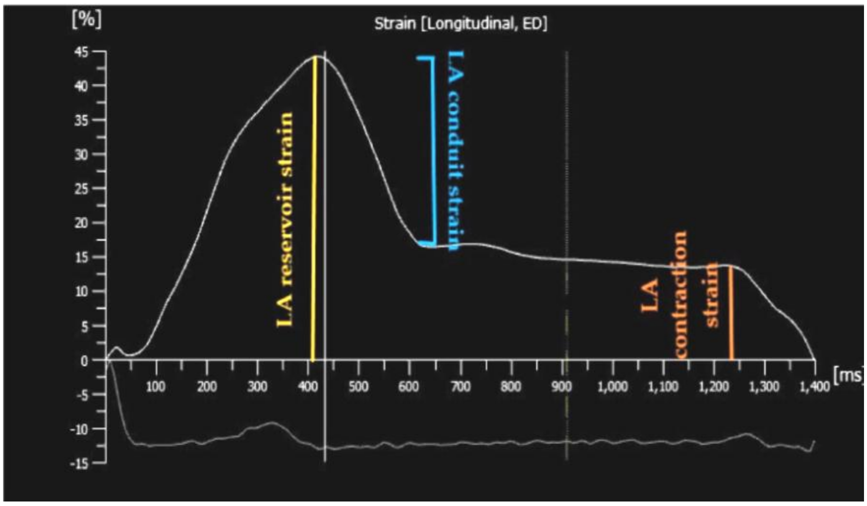

Figure (2): Speckle tracking analysis and strain measurements during the three phases of left atrial cycle **(42)**

LA function cannot be determined by a single measurement; instead, clinical investigations have employed a number of factors. However, the reservoir strain best captures the overall function. (14)

Over the past 20 years, numerous working parties have evaluated the normal reference value for LA reservoir strain. All things considered, it can be said that the typical value of LA reservoir strain differed among publications based on factors such as vendor, sample size, ECG gating, age, gender, and racial disparities. The usual reference reservoir strain value with the lowest reported value was 23 percent. (43) Atrial contraction is absent in AF patients, but reservoir and conduit strain are reduced. Because of LA fibrosis and decreased compliance, changes in the reservoir function may be identified even prior to the onset of AF. Evaluation of the function prior to a procedural technique may be a powerful predictor of success since LA speckle tracking's reservoir function has an inverse linear connection with cardiac magnetic resonance late gadolinium enhancement, which detects fibrosis. (44) Before LA size changes become apparent, LA strain identifies early mechanical dysfunction.

LA compliance and fibrosis, which are important in the pathophysiology of AF, are reflected in reservoir strain. Atrial fibrosis is consistently correlated with reduced LA strain. Both globally and regionally, the correlations are valid, and strain may even be a better predictor of fibrosis and clinical outcomes than conventional morphologic measurements. (45) It has been demonstrated that LA reservoir strain can identify early atrial dysfunction prior to physical hypertrophy. better risk prediction outside of LA size and decreased LA reservoir strain independently predicted incident AF. (46) According to Camelli et al. (47), there is a correlation between impaired LA strain and the initiation and recurrence of AF after cardioversion or ablation, suggesting that it has prognostic significance. These results highlight a paradigm shift: for earlier and more precise AF risk categorization, functional indicators are being used instead of just anatomical measurements.

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