Electrocardiographic Markers of Atrial Cardiomyopathy Predict Cardioembolic Stroke and Occult Atrial Fibrillation: Insights from a Prospective Stroke Cohort

Les marqueurs électro-cardiographiques de la cardiomyopathie atriale prédictifs d'AVC cardioembolique et de fibrillation atriale occulte

Amine Bahloul 1 Oussama Haddar 1 Nadia Bouattour2 Mariem Jabeur1 Selma Charfeddine1 Mariem Dammak2 Leila Abid 1

1. *Hedi Chaker University Hospital, Cardiology Department, Sfax, Tunisia*
2. *Habib Bourguiba University Hospital, Neurology Department, Sfax, Tunisia*

Summary

This paper reviewed the principal electrocardiographic manifestations of atrial cardiomyopathy, including P-wave terminal force in lead V1 (PTFV1), P-wave duration, P-wave dispersion, and interatrial block. These biomarkers reflect atrial electrical remodeling resulting from fibrosis, conduction slowing, and structural disorganization.

In our prospective bicentric cohort of patients with ischemic stroke, PTFV1 and P-wave dispersion independently predicted cardioembolic stroke and occult atrial fibrillation. Specifically, a PTFV1 ≥3100 ms·µV and a P-wave dispersion ≥55 ms were retained in the final multivariable model and incorporated into the ES²CRYP score from a Tunisian cohort.

Keywords

Atrial cardiomyopathy; Cardioembolic stroke; Occult atrial fibrillation; Electrocardiography; P-wave abnormalities; P-wave dispersion; Atrial electrical remodeling; ES²CRYP score.

Résumé

Cette étude a analysé les principales manifestations électrocardiographiques de la cardiomyopathie atriale, notamment la force terminale de l'onde P en dérivation V1 (PTFV1), la durée de l'onde P, la dispersion de l'onde P et le bloc interauriculaire. Ces biomarqueurs reflètent le remodelage électrique atrial lié à la fibrose, au ralentissement de la conduction et à la désorganisation structurelle du myocarde atrial.

Dans notre cohorte prospective bicentrique de patients ayant présenté un accident vasculaire cérébral ischémique, le PTFV1 et la dispersion de l'onde P se sont révélés être des prédicteurs indépendants de l'AVC cardioembolique et de la fibrillation atriale occulte. Plus précisément, un PTFV1 ≥ 3100 ms·µV et une dispersion de l'onde P ≥ 55 ms ont été retenus dans le modèle multivarié final et intégrés au score ES²CRYP, développé à partir d'une cohorte tunisienne.

Le score ES²CRYP comprend les variables suivantes : âge ≥ 75 ans, sexe féminin, strain atrial gauche (PALS) ≤ 26,5 %, absence de maladie coronarienne, charge en contractions atriales prématurées ≥ 400/24 h, dispersion de l'onde P ≥ 55 ms et PTFV1 ≥ 3100 ms·µV.

Ce travail met en évidence l'importance du remodelage électrique atrial dans la physiopathologie de la cardiomyopathie atriale et souligne la valeur pronostique des anomalies de l'onde P pour l'identification des patients à risque d'AVC cardioembolique et de fibrillation atriale occulte.

Mots-clés

Cardiomyopathie atriale ; Accident vasculaire cérébral cardioembolique ; Fibrillation atriale occulte ; Électrocardiogramme ; Onde P ; Dispersion de l'onde P ; Remodelage électrique atrial ; Score ES²CRYP.

Correspondance

Amine Bahloul

INTRODUCTION

Electrocardiography remains the most accessible and widely available tool for the assessment of atrial electrical remodeling. Although traditionally used for the diagnosis of overt arrhythmias, the standard 12-lead ECG contains valuable information regarding atrial structure, conduction, and electrophysiological integrity. Atrial fibrosis, chamber enlargement, anisotropic conduction, and electrical heterogeneity all affect P-wave morphology and duration. Consequently, several ECG biomarkers have emerged as surrogate markers of atrial cardiomyopathy and predictors of atrial fibrillation (AF), ischemic stroke, and cardiovascular events (1–3).

Among these biomarkers, P-wave terminal force in lead V1 (PTFV1), P-wave duration, P-wave dispersion (PWD), and interatrial block (IAB) have received particular attention (4–11).

PATHOPHYSIOLOGICAL BASIS

The normal P wave reflects depolarization of both atria. Electrical activation begins in the sinoatrial node and propagates through the right atrium, Bachmann bundle, and left atrium. Fibrosis and atrial remodeling disrupt this process by slowing conduction velocity, increasing conduction heterogeneity, creating conduction block, and promoting electrical instability (1–3). The ECG therefore becomes a non-invasive window into atrial pathology.

P-WAVE TERMINAL FORCE IN LEAD V1 (PTFV1) (FIGURE 1)

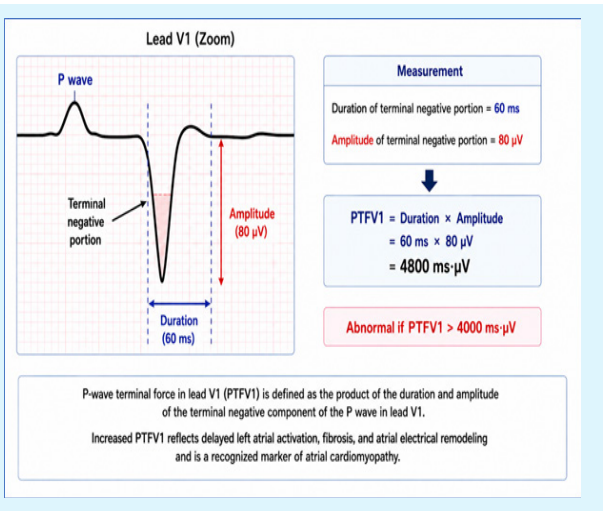

Figure 1. Measurement of P-Wave terminal force on V1 Lead (PTFV1)

PTFV1 is measured in lead V1 as the product of the amplitude and duration of the terminal negative component of the P wave and is expressed in ms·µV.

Traditionally, PTFV1 >4000 ms·µV has been considered abnormal (5,18).

Pathophysiological Significance

An increased PTFV1 reflects delayed left atrial activation, left atrial enlargement, fibrosis, and electrical remodeling (1,2,18). Histopathological studies have demonstrated strong correlations between elevated PTFV1 values and atrial structural abnormalities (1,2).

Clinical Evidence

The ARIC study demonstrated that abnormal PTFV1 independently predicts incident AF, ischemic stroke, and cardiovascular mortality (5). Several subsequent studies confirmed that elevated PTFV1 predicts cardioembolic stroke even in the absence of documented AF (6).

Kamel et al. demonstrated that ECG-defined left atrial abnormality was associated with ischemic stroke independently of AF, supporting the concept of atrial cardiopathy as a thromboembolic substrate (6).

The ARCADIA trial subsequently incorporated PTFV1 ≥5000 ms·µV as one of the criteria defining atrial cardiopathy in patients with embolic stroke of undetermined source (17,18).

PTFV1 and ES²CRYP

In our cohort, PTFV1 ≥3100 ms·µV emerged as an independent predictor of occult AF and cardioembolic stroke and was incorporated into the ES²CRYP score (19). This threshold differs from previously reported values, probably reflecting differences in population characteristics and ECG measurement methodology.

P-WAVE DURATION

P-wave duration represents total atrial depolarization time. Normal values are generally <120 ms, whereas prolonged values are ≥120 ms (4,9).

Mechanisms

P-wave prolongation results from atrial enlargement, fibrosis, conduction slowing, and aging-related remodeling (1,2). Longer conduction pathways and disrupted electrical propagation increase depolarization time.

Clinical Implications

Prolonged P-wave duration predicts incident AF, ischemic stroke, and cardiovascular mortality (4,7,8). Increased P-wave duration reflects delayed interatrial conduction and is frequently observed in patients with atrial cardiomyopathy and paroxysmal AF (7,8).

In our cohort, patients with cardioembolic stroke exhibited significantly longer P-wave duration than patients with non-cardioembolic stroke.

P-WAVE DISPERSION (PWD) (FIGURE 2)

P-wave dispersion is calculated as Maximum P-wave duration – Minimum P-wave duration across the 12 ECG leads.

Normal values generally range between 20 and 40 ms, whereas values >40–50 ms suggest abnormal atrial conduction (7,8).

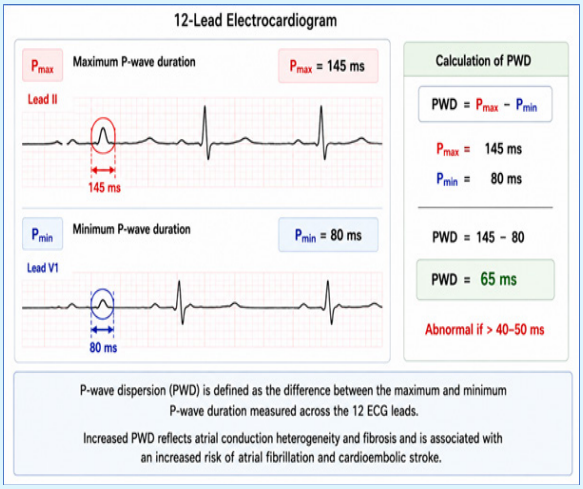

Figure 2. Measurement of P-Wave dispersion (PWD)

Physiological Basis

PWD reflects conduction heterogeneity, regional conduction delay, and electrical anisotropy. Atrial fibrosis creates areas of slow conduction that increase dispersion and promote reentry mechanisms (1,2).

Clinical Evidence

Increased PWD predicts paroxysmal AF, recurrent AF, and cardioembolic stroke (7,15). Meta-analyses have demonstrated significant associations between elevated PWD and future AF occurrence (7).

Recent studies in cryptogenic stroke populations showed that PWD independently predicts AF detection after prolonged rhythm monitoring (15).

Role in ES²CRYP

In our study, P-wave dispersion ≥55 ms independently predicted occult AF and cardioembolic stroke and was retained in the final ES²CRYP model (19). Patients with cardioembolic stroke exhibited significantly higher P-wave dispersion values than non-cardioembolic stroke patients.

INTERATRIAL BLOCK (IAB) (FIGURE 3)

Interatrial block reflects delayed conduction between the right and left atria.

Partial IAB is defined by:

- P-wave duration ≥120 ms

Advanced IAB is defined by:

- P-wave duration ≥120 ms
- Biphasic (+/–) morphology in inferior leads

This pattern is commonly referred to as Bayés syndrome (9,10).

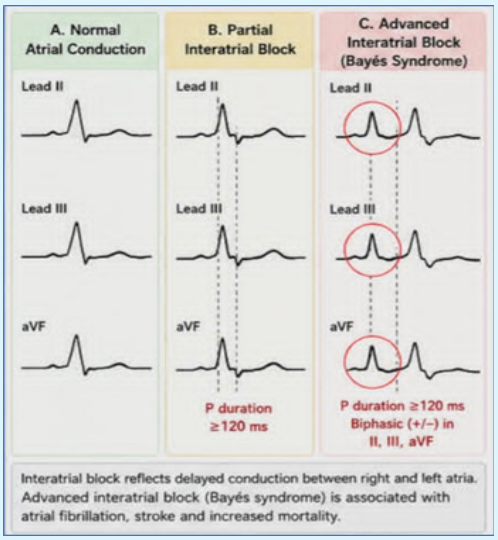

Figure 3. Electrocardiographic Patterns of Interatrial Block

Mechanism

Interatrial block is usually caused by fibrosis of Bachmann bundle, left atrial remodeling, and aging-related conduction abnormalities (9,10).

Clinical Importance

Advanced interatrial block is associated with AF, stroke, dementia, and mortality (9–12,14). Bayés de Luna and colleagues proposed that advanced IAB represents a distinct clinical entity linking atrial remodeling and thromboembolic complications (9,10).

SomeinvestigatorsconsiderIABadirectelectrocardiographic manifestation of atrial cardiomyopathy (1,9).

In our cohort, advanced interatrial block was significantly more frequent among patients with cardioembolic stroke.

COMBINING ECG BIOMARKERS

No single ECG marker adequately characterizes atrial cardiomyopathy. Combining multiple biomarkers improves predictive performance and allows a more comprehensive assessment of atrial electrical remodeling (1,2,16). (figure 4)

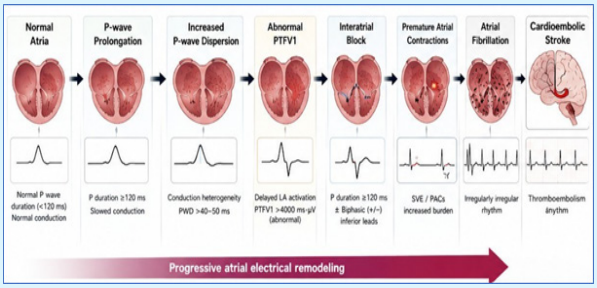

Figure 4. Electrocardiographic remodeling continiul in atrial cardiomyopathy

Examples include PTFV1, P-wave dispersion, P-wave duration and Interatrial block

This multimarker strategy forms the basis of modern electrocardiographic phenotyping and contributed to the development of the ES²CRYP score (19) . (figure 5)

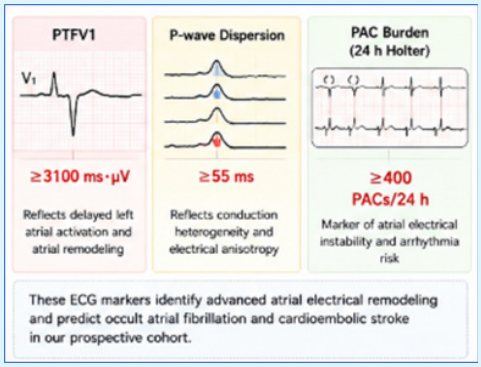

Figure 5. Electrocardiographic Components of the ES²CRYP Score

CONCLUSION

ECG biomarkers provide a simple, inexpensive, and widely available method for detecting atrial cardiomyopathy. PTFV1, P-wave duration, P-wave dispersion, and interatrial block reflect distinct aspects of atrial electrical remodeling and contribute significantly to risk stratification for AF and cardioembolic stroke (5–15,18).

In our prospective bicentric cohort, PTFV1 ≥3100 ms·μV and P-wave dispersion ≥55 ms emerged as independent predictors of cardioembolic stroke and occult AF and were incorporated into the ES²CRYP score

REFERENCES

1. Goette A, Kalman JM, Aguinaga L, et al. EHRA/HRS/APHRS/SOLAECE expert consensus on atrial cardiomyopathies: definition, characterization, and clinical implication. Europace. 2016;18(10):1455-1490.
2. Kamel H, Okin PM, Elkind MSV, Iadecola C. Atrial cardiopathy: a broadened concept of left atrial thromboembolism beyond atrial fibrillation. Future Cardiol. 2015;11(3):323-331.
3. Freedman B, Kamel H, Van Gelder IC, Schnabel RB. Atrial cardiomyopathy: a major challenge in modern cardiovascular medicine. Circulation. 2020;142(1):20-23.
4. Benjamin EJ, D'Agostino RB, Belanger AJ, et al. Left atrial size and the risk of stroke and death. Circulation. 1995;92(4):835-841.
5. Soliman EZ, Alonso A, Goff DC Jr, et al. Electrocardiographic markers and prediction of atrial fibrillation. Circulation. 2009;119(25):3163-3170.
6. Kamel H, Soliman EZ, Heckbert SR, et al. P-wave morphology and the risk of incident ischemic stroke. Stroke. 2014;45(9):2786-2788.
7. He J, Tse G, Korantzopoulos P, et al. P-wave indices and risk of ischemic stroke: a systematic review and meta-analysis. Stroke. 2017;48(8):2066-2072.
8. Maheshwari A, Norby FL, Soliman EZ, et al. Electrocardiographic markers and risk of atrial fibrillation and stroke. J Am Heart Assoc. 2019;8:e014459.
9. Bayés de Luna A, Platonov P, Cosio FG, et al. Interatrial blocks: a separate entity from left atrial enlargement. J Electrocardiol. 2012;45(5):445-451.
10. Conde D, Seoane L, Gysel M, et al. Bayés syndrome and thromboembolic risk. Clin Cardiol. 2015;38(7):427-432.

11. O'Neal WT, Zhang ZM, Loehr LR, et al. Electrocardiographic advanced interatrial block and atrial fibrillation risk in the ARIC Study. Am J Cardiol. 2016;117(11):1755-1759.
12. Kishore A, Vail A, Majid A, et al. Detection of atrial fibrillation after ischemic stroke or transient ischemic attack. Stroke. 2014;45(2):520-526.
13. Gladstone DJ, Spring M, Dorian P, et al. Atrial premature beats predict atrial fibrillation in cryptogenic stroke. N Engl J Med. 2014;370(26):2467-2477.
14. Larsen BS, Kumarathurai P, Falkenberg J, et al. Excessive supraventricular ectopic activity and the risk of atrial fibrillation and stroke. Circulation. 2015;131(25):2111-2119.
15. Himmelreich JCL, Lucassen WAM, Heugen M, et al. Predictive value of supraventricular ectopic activity for atrial fibrillation. J Am Coll Cardiol. 2019;74(3):346-357.
16. Hindricks G, Potpara T, Dagres N, et al. ESC Guidelines for the management of atrial fibrillation. Eur Heart J. 2024.
17. Kamel H, Longstreth WT Jr, Tirschwell DL, et al. The ARCADIA Trial. Int J Stroke. 2019;14(2):207-214.
18. Yaghi S, Kamel H, Elkind MSV. Atrial cardiopathy: mechanisms and clinical implications. Lancet Neurol. 2021;20(6):494-506.
19. Bouttour N, Haddar O, Bahloul A, Triki F, Ghrab A, Damak M, et al. A new clinical score predictive of paroxysmal atrial fibrillation in ischemic stroke patients (P2-13.014). Neurology. 2025;104(7 Suppl 1):3449. doi:10.1212/WNL.0000000000211018.