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Why the P-wave should be measured precisely?

Dlaczego załamek P powinien być dokładnie mierzony?

Jacek Marcin Zawadzki[1], Grzegorz Zawadzki[2], Jadwiga Radziejewska[3], Jacek Jerzy Gajek[4]

[1]Department of Cardiology, Kłodzko County Hospital, Kłodzko, Poland
[2]Students Scientific Society, Department of Emergency Medical Service, Wrocław Medical University, Wrocław, Poland
[3]Klodzko County Hospital, Kłodzko, Poland
[4]Department of Emergency Medical Service, Wroclaw Medical University, Wrocław, Poland

Abstract

The electrophysiological activity of the heart is recorded and presented in form of electrocardiogram (ECG). In 1998 the concept of the P-wave dispersion as the risk factor for atrial fibrillation recurrence was introduced. The presented review aims to prove the P-wave dispersion is an artifact of low accuracy in P-wave measurement, basing on the overview of the publications and the own research in this field.

By comparing and contrasting various publications on this topic, the authors observed that it was the imprecise measurement method that resulted in different durations of all P-wave parameters in contrast with the precise measurements. It was indicated that the value of the imprecise P-wave dispersion correlated highly with the maximal P-wave duration measured similarly. In contrast with the imprecise measurement method the minimal and the maximal duration of the P-waves, measured accurately, were almost identical.

The studies and the methodological considerations indicate that the P-wave dispersion is a derivative of the imprecise measurement of the ECG recording, inconsistent with the physics rules describing the flow of electric current. The results confirm the authors' observation that the precise measurement of the P-wave makes the phenomenon of dispersion no longer exists.

Unfortunately, only a few researchers dare to question the phenomenon of the P-wave dispersion. The discussion should continue, because the P-wave parameters are the data of great importance, as they reflect the dimensions of the atria, electrical conductivity and the condition of the muscle.

Key words: P-wave duration, P-wave dispersion, total atrial activation time

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The P-wave

The electrophysiological activity of the working myocardium is recorded by the system of simultaneous electrocardiographic leads and presented in the form of an electrocardiogram (ECG) [1]. The morphology of the ECG recording in a given lead is the resultant direction of the depolarization wave propagation and depends on the spatial range, within which a given lead can register an impulse [2]. The registration is performed in all leads simultaneously, i.e. a phenomenon begins and ends at the same time parallelly in all twelve leads [3]. In the case of the perpendicular activation vector in the bipolar electrode and the parallel vector in case of the unipolar electrode, the specific lead records an isoelectric line [4]. Sino-atrial depolarization begins in the upper part of the sinoatrial node, which is

Address for correspondence: Jacek Zawadzki MD, Oddział Kardiologii, Szpital ZOZ Kłodzko, ul. Szpitalna 1a, 57–300 Kłodzko, Poland, e-mail: jacekzawadzkimed@gmail.com

located in front of the superior vena cava to the right atrium. The impulse spreads down across the right atrium towards the left atrium through the conducting tissue called the Bachmann bundle. This leads to rapid activation of the right and left atrium, resulting in a single, monophasic P-wave in the electrocardiogram [5]. The duration of the P-wave is determined by the conduction of the depolarization from the sinoatrial node to the lower part of the left atrium. This parameter can be called "total atrial conduction time", which can also be assessed by the tissue Doppler examination [6]. The P-waves have been used in several studies as indicators helping to distinguish people with cardiovascular diseases from the healthy reference groups [7].

The particular attention should be paid to the most important fact mentioned earlier: the onset of each ECG event occurs at exactly the same time in each lead. It should be remembered that the direction of the momentary electrical vector does not make the deflection visible in each lead. The P-wave duration may differ on the ECG due to the presence of invisible (isoelectric/low amplitude) fragments in some leads. The presence of these isoelectric fragments is the consequence of the impulse flow direction considered in a specific plane. Since the direction of the atrial depolarization and the degree of atrial synchrony have a large impact on the P-wave duration, most studies select the specific leads to assess the P-wave, including the most commonly used: II and V1 [8].

The duration of individual elements of the electrocardiogram is always a derivative of two components — the conduction velocity and the distance to travel. Under the conditions of the heart muscle, both of these elements are dependent on the physiological-biological variability but most often associated with typical pathologies. The size of the atria increases usually due to systemic or pulmonary hypertension [9]. The conduction-velocity is maximal under physiological conditions and decreases in the course of various pathologies. The typical examples are hypertension-related fibrosis, inflammatory lesions, ischemic scar formation and myocardial necrosis. A less common example could be any myocardial-storage disease [10]. The increase in the conduction-velocity within heart muscle may be associated with raised body temperature, increased sympathetic activity or hyperthyroidism [11].

The duration of the P-wave depends on the size of the atria and the electrophysiological properties of the atrial muscle. The additional factor that may significantly affect the morphology and the duration of the P-wave is the presence of the interatrial conduction blocks [12]. The enlargement is assessed using ultrasound, and the interatrial conduction blocks are spotted by the specific P-wave morphology. The loss in cardiomyocytes, associated with numerous pathologies, causes a decrease in the amplitude of the atrial depolarization signal. The pathophysiological processes described above mean that the P-waves in the electrocardiogram are influenced by numerous changes — their duration and morphology, and the reduced signal amplitude generate additional difficulties in assessing the beginning and — in particular — the end of the deflections [13]. The prolongation of the P-wave duration has a significant meaning concerning the patient's prognosis, the severity of atrial arrhythmias or the ability to maintain sinus rhythm [14]. The accurate measurement of the P-wave duration, regarding the numerous difficulties in performing it, may be even crucial in searching for optimal therapies as well as in the prognosis assessment — hence, the precision is particularly important. Because of this reason, the attention is devoted to the issue of dispersion, which in the authors' opinion is not only a dead end in searching for the effective AF recurrence predictor, but also distorts the correct understanding of changes in the P-wave.

The P-wave dispersion

In their 1998 publication in the "American Heart Journal", Dilaveris et al. [15] introduced the concept of the P-wave dispersion as a risk factor of atrial fibrillation (AF), calculated as the difference between the maximal and minimal duration of the P-wave in two different leads of a 12-lead ECG. The study group consisted of 60 patients, aged 59.0 ± 12.0 years, with a history of paroxysmal AF, and the control group of 40 healthy comparable individuals. It should be emphasized that the groups were very well matched in terms of sociodemographic parameters, left atrium size, atrioventricular conduction time and left ventricular ejection fraction. The P-wave dispersion was calculated the following way: "The 12-lead electrocardiogram was recorded at a paper speed of 50 mm/s and 1 mV/cm standardization. [...] The measurements of the P-wave duration were performed manually by two of the investigators without knowledge of patient assignment by using callipers and a magnifying lens (10-fold magnification) [...]", the studied groups also differed in the duration of the P-wave (123 ± 16 ms vs. 101 ± 10 ms, $p < 0.0001$). The maximal P-wave value of 110 ms and the P-wave dispersion value of 40 ms were the factors differentiating between patients and the control group, with the positive predictive accuracy of 89%. In patients group the dispersion was 49 ± 15 ms and in the control group 28 ± 7 ms, which was statistically significant. The study concluded that P-wave dispersion is an indicator of heterogeneous, non-homogeneous and anisotropic atrial conduction. In a study including patients with a history of paroxysmal AF, the duration of the P-wave was much longer, and so was the P-wave dispersion. Hence, the authors suggested the P-wave dispersion is a separate, independent electrocardiographic marker of AF risk. This methodology significantly violates the basic principle of

Table 1. The exemplary studies on the P wave dispersion (based on [17–24])

Authors	Study group (N)	Study age (years)	PWD study [ms]	Controls (N)	Controls, age (years)	PWD controls [ms]	F (N)	M (N)	Methodology
Dogan et al. [17]	64	61.5 ± 10.1	53.2 ± 3.9 vs. 40.3 ± 4.7 (AF vs. sinus rhythm)	None	None	None	34	30	50 mm/s, 20 mm/mV, manually, magnifying lens
Salah et al [18]	198	57.0 ± 8.0	40.7 ± 1.7 vs. 36.6 ± 3.2 (AF vs. sinus sinus rhythm)	None	None	None	48	150	50 mm/s, 2 mV/cm, manually
Kollu et al. [19]	133	60.8 ± 14.2	45.9 ± 12.4	32	61.0 ± 12.9	21.2	66	99	25 mmn/s, manually
Yılmaz et al. [20]	125	37.9 ± 12.1	(Pretranspl.) 43.4 ± 7.3 vs. (transpl.) 37.6 ± 7.3	109	38.98 ± 11.7	31.6 ± 7.8	95	139	25 mm/s, 10 mm/mV, manually, × 400 zoom with Photoshop — rastric graphics
Huang et al. [21]	439	66.0 ± 12.0	88.8 ± 21.7	None	None	None	165	274	25-mm/s, 1-mV/cm, and 100-Hz/manually, Image Tool 3.0
Abdellah, Nagary [22]	110	58.9 ± 9.7	42.8	None	None	None	36	74	50 mm/s with 20 mm/mV magnifying lens and 0.5 mm scale precision ruler (Biotronic®)
Yamada et al. [23]	55	54.0 ± 18.0	26.6 ± 9.5	57	48.0 ± 21.0	14.8 ± 6.7	40	72	Automatically filtered signal analysis, every 1 ms
Rosiak et al. [24]	130	56.9 ± 12.0	34.5 vs. 19.7 (AF vs. non-AF)	None	None	None	30	100	Signal-averaged electrocardiography (SAECG), Burdick system

PWD study — the P wave dispersion [ms] in the study group; PWD controls — the mean P wave dispersion [ms] in the control group; F — females; M — males; Methodology — the methods of taking the measurements, directly used to calculate the dispersion; AF — atrial fibrillation

electrocardiography — each ECG event begins and ends at exactly the same time, parallelly in each lead. It is not a principle that can be questioned in any way, because it results directly from the laws of physics that describe the flow of electric current. Nor will this problem be eliminated by 10× magnification, 50 mm/s paper speed, or 1 mV/cm gain used by Dilaveris et al. [15].

Over the years, the author and his partners have improved the quality of their measurements, taking them manually, with the help of electrophysiological system [16], however, the method of measuring and understanding remained the same. The theory of the P-wave dispersion, developed in 1998, is based on two elements — the erroneous assumptions and the imprecise way of taking measurements. With the mentioned speed and magnification there aren't many details visible in the ECG. What's more — the assumptions of this theory have been constantly duplicated. Over the years, the authors published more studies on this subject, using more and more precise measurement tools. Paradoxically, this did not allow them to revise their position. More flattened fragments of the P-waves were treated as the extinction of the impulse in a given lead, so that the facts could confirm the theory, with the assumptions made *a priori*.

The followers

So far, many studies which keep duplicating the same erroneous methodology and keep reproducing the same erroneous results have been carried out. For the clarity of the presentation, the data was gathered in Table 1 [17–24].

The table presents various papers dealing with P-wave dispersion, as the parameter, taken into consideration with regard to different topics. Interestingly, the P-wave dispersion is the shortest in the work published by Yamada et al. [23]. The authors used an automatic software which helped to precisely assess the beginning and the end of the P-wave (every 1 ms analysis). In case of the other works, the measurements were taken manually with less precise parameters (25–50 mm/s, 10–20 mm/mV) and/or using

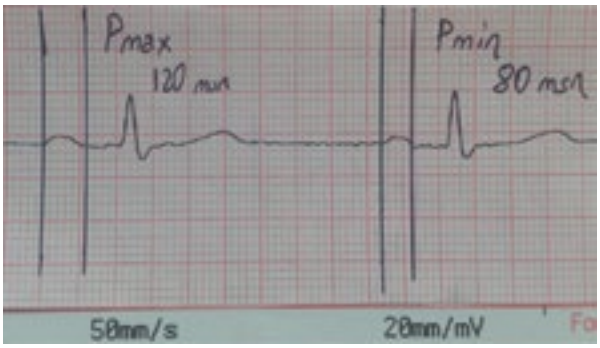

Figure 1. Doubly wrong measurement method — the dispersion of the P-wave should be determined by contrasting the very same P-wave parallelly in many leads, by subtracting the so-called minimum P-wave duration from the maximum one, at the same time. First mistake: the author contrasted two **following** P-waves within the same lead, which makes no sense. Second mistake: for this purpose, the author used a pen and the parameters of 50 mm/s; 20 mm/mV, which are far too imprecise

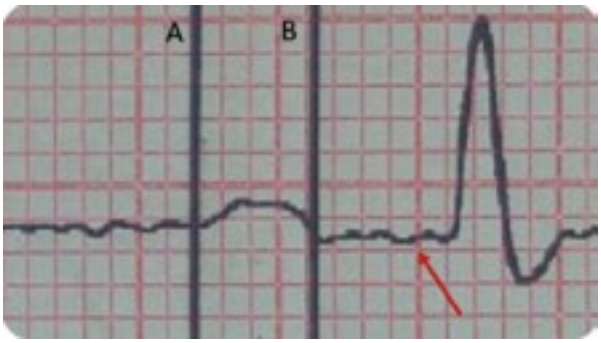

Figure 2. The line (A) marking the beginning of the P-wave (too early). The line (B) marking the end of the P-wave (also too early — red arrow indicate the real end of the P-wave). The duration of the P-wave, according to the author's measurements is about 80 ms, whereas according to ours — it's twice as long, i.e. ~160 ms

the rastric graphics zoom which is less precise than the vector one.

Errors and distortions

To prove how important is the incorrect methodology for the P-wave dispersion theory, the example of the work by Akcay et al. [25] will be used, which touches the influence of moderate height on the various ECG parameters and the P-wave dispersion. The authors would like to draw attention to the phenomenon introduced by Dilaveris et al. in 1998 [15]. The visual differences in the P-waves in many leads are so subtle that they can be easily ignored, even if the magnifying glass is used for measurements. As a result, the measurements appear somewhat scattered. The authors' position is very easy to defend because the author used a hand-tool to mark the beginning and end of the P-wave in the electrocardiogram, drawing the lines that are not only thicker than the isoelectric line itself but also miss the right spot in which the very first deviation of the P-wave occurs. Below attached is the original image from Ackay's et al. work (Figure 1) and the image to point out the details of methodology (Figure 2). At the same time, Dilaveris et al. used very similar tools when creating his theory. Despite the advances in technology, the researchers decided to use the same tools as in the initial study (although more precise measurement tools were available at that time), which resulted in analogous distortions that 22 years ago were called the P-wave dispersion.

Moreover, Akcay et al. made a double mistake in his study because — contrary to the original concept — he used only one and the same ECG lead to measure the difference in the duration of the P-wave (P_{max}–P_{min}), which is additionally methodologically flawed. The differences in measurement observed in one lead are present, because the second P-wave is an atrial extrasystole with different P-wave morphology, which indicates the major misunderstanding of the topic.

There's no dispersion and why so?

In 2015, the team of Zimmer et al. [26], based on the material presented at the Europace in Milan, concluded that the dispersion of the P-wave, which was assessed using the standard parameters, is simply a measurement artefact. After improving the precision, the dispersion no longer exists, i.e. it is nothing but an apparent measurement phenomenon. The authors examined 94 patients (42 F, 52 M) aged 63 ± 14-years-old (26–89) who were subjected to the procedures under the control of the LABSYSTEM™ Pro system, which, thanks to its precision, allowed to assess the P-waves at the parameters of 200 mm/s, magnification 128–256×. The results of the measurements were contrasted with those obtained with the parameters of 50 mm/s and 8× magnification. All measurements were repeated three times. The test results clearly showed, that with the less precise parameters, the measurements showed: P_{max} = 72.7 ms, P_{min} = 26.4 ms, P_{disp} = 45.14 ms, while very precise measurements showed: P_{max} = 115.36 ms, P_{min} = 114.10 ms, P_{disp} = 1.24 ms. Based on these results, it can be stated directly — dispersion is just a phenomenon which does not exist when the measurements are approached with the appropriate precision. The clinical utility of this parameter can be explained by its direct dependence on the P_{max} (P_{max}/P_{disp} correlation), which reflects the enlargement of

the left atrium and/or conduction disturbances. For this reason, dispersion, even though it does not exist per se, will show the apparent clinical utility as it is based directly on the P_{max}.

In 2020, based on this study materials, there was published a work which included 104 patients (48 F, 56 M), aged 63 ± 14-years-old, who were subjected to various electrophysiological procedures, and then underwent a detailed analysis [27]. The duration of the P-wave was measured twice — first at 50 mm/s, 8× magnification, and the second time at 200 mm/s and 64–256×. Insufficiently precise measurements resulted in P_{max} 105.1 ± ± 22.1 while precise measurements revealed the P_{max} of 134.0 ± 21.3 ($p < 0.001$). The dispersion of the P-wave measured in a less precise manner was 44.1 ± 16.8 ms while the more accurate measurements showed dispersion of 2.8 ± 3.4 ms ($p < 0.0001$). The correlation between the imprecise maximal P-wave duration and imprecise minimal P-wave duration was $r = 0.664$ ($p < 0.05$). The correlation between the imprecise maximal duration of the P-wave and the imprecisely measured dispersion of the P-wave was $r = 0.612$ ($p < 0.05$). The correlation between precise maximal and precise minimal P-wave duration was almost 1.0 ($r = 0.987$, $p < 0.05$).

To furtherly prove the point, Zawadzki et al. [28] were successful with the work accepted at the European Society Cardiology Congress 2020, which described the results of an analysis of 150 patients (89 F, 61 M) assessed using an electrophysiological system. The authors went one step further — the duration of P-waves was assessed twice (first at 50 mm/s, 16×, then at 200 mm/s, 128–256× parallelly in all leads) by 3 independent researchers, measuring the dispersion of the P-wave in three groups: AVNRT (50 patients), AFL (50 patients) and AF (50 patients). The duration of the P-waves at (50 mm/s, 16×) were 78.2 ± 10.1 respectively; 74.3 ± 11.8 ms; 98.5 ± 21.6 ms for AVNRT, AFL and AF and at (200 m/ms, 128–256×) the results were 121.2 ± ± 15.2 ms; 123 + 22.2 ms; 141.1 ± 22.8 ms. The dispersion of the P-wave at (50 mm/s, 16×) was 46.5 ± 16.9 ms, respectively; 48.5 ± 20.3 ms; 55.8 ± 23.3 ms for AVNRT, AFL and AF, and at (200 mm/s, 128–256×) the results were 4.0 ± 3.4 ms; 4.1 ± 3.9; 4.6 ± 3.7 ms.

But we still believe...

Interestingly, since the first studies that proved the methodology of P-wave dispersion research was wrong, only a few authors have taken this point of view into account in their publications. Chávez-González et al. [29] cited it in their studies on the P-wave dispersion. Surprisingly, just a few lines below, the authors concluded: "Even so, we still believe that there is sufficient evidence to support the importance of P-wave dispersion in clinical practice and continuation of research". This sentence proves that when the theory has been firmly established in the scientific world over the years, the restoration of the precision is not enough to prove that the arguments are false when they are based on faith or beliefs.

Summary

In conclusion, the presented studies and the methodological considerations indicate that the P-wave dispersion is a derivative of the imprecise measurement of the ECG recording, inconsistent with the physics rules describing the flow of electric current. These results confirmed the observation, that as soon as the precision of the P-wave measurement is increased, the phenomenon of dispersion no longer exists — it is only an optical illusion, a technical error resulting from insufficiently precise hardware settings that were available in the 90s of XX^{th} century. As the dispersion is connected directly with the duration of the P-wave, oneknows that the longer duration of the P-wave is, the worse condition of the atria is. It would be much simpler and more accurate to turn the name of the "P-wave dispersion", into the "degree of atrial destruction". Even a better idea would be to calculate the "total atrial activation time".

The P-wave dispersion theory has a firmly established position in the scientific world and, unfortunately, a few researchers dare to question it, despite justified assumptions. The discussion, however, should be continued, because the P-wave parameters are the data of great importance, as they reflect the dimensions of the atria, electrical conductivity, its nature, and more importantly the condition of the ground.

The presented results show with certainty that the theory of the P-wave dispersion is wrong and there can be no doubts about it. The authors are aware that the statement of this fact will rise the hot opposition from many other authors. To finally consolidate this position, a scientific work based on a special algorithm designed exclusively for this type of measurements will be published shortly.

Streszczenie

Aktywność elektrofizjologiczna serca jest rejestrowana i prezentowana w postaci zapisu elektrokardiograficznego (EKG). W 1998 roku wprowadzono koncepcję dyspersji załamka P jako czynnika ryzyka nawrotu migotania przedsionków. Celem pracy autorów było wykazanie, na podstawie przeglądu publikacji i badań własnych w tej dziedzinie, że dyspersja załamka P jest artefaktem wynikającym z niskiej dokładności pomiaru załamka P.

Porównując różne publikacje na ten temat, autorzy zauważyli, że to przede wszystkim nieprecyzyjna metoda pomiaru spowodowała różne czasy trwania wszystkich parametrów załamka P w przeciwieństwie do pomiarów precyzyjnych. Dowiedziono ponadto, że wartość nieprecyzyjnie zmierzonej dyspersji załamka P silnie korelowała z maksymalnym czasem trwania załamka P mierzonym w analogiczny sposób. W przeciwieństwie do nieprecyzyjnej metody pomiaru minimalne i maksymalne czasy trwania załamków P, mierzone dokładnie, były prawie identyczne.

Z przeprowadzonych badań i rozważań metodologicznych wynika, że dyspersja załamka P jest pochodną nieprecyzyjnego pomiaru zapisu EKG, niezgodnego z zasadami fizyki opisującymi przepływ prądu elektrycznego. Wyniki jednoznacznie potwierdzają obserwację autorów wskazującą, że precyzyjny pomiar załamka P sprawia, że zjawisko jego dyspersji przestaje istnieć.

Niestety tylko nieliczni badacze odważyli się zakwestionować istnienie zjawiska dyspersji załamka P. Dyskusję należy jednak kontynuować, ponieważ parametry załamka P są danymi o dużym znaczeniu, gdyż odzwierciedlają wymiary przedsionków, przewodnictwo elektryczne i stan mięśnia.

Słowa kluczowe: czas trwania załamka P, dyspersja załamka P, całkowity czas aktywacji przedsionków

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