

The P wave dispersion—one pixel, one millisecond

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The electrophysiological activity of the heart is recorded and presented in form of electrocardiogram (ECG). In 1998 the concept of P wave dispersion as the risk factor for atrial fibrillation (AF) recurrence was introduced. It was calculated as the difference between the longest and the shortest P wave. The aim of our study is to prove that the P wave dispersion is an artifact of low accuracy in P wave measurement. The study included 186 patients (78M/108F) aged 59.7 ± 12.9 years, undergoing various electrophysiological procedures. The P wave was measured twice: first, at the paper speed of 50 mm/s, enhancement $8 \times$ (standard – imprecise) and the second time at 200 mm/s, $64-256 \times$ (precise). The imprecise measurement method resulted in different duration of all P wave parameters in comparison with precise measurement. The difference between ΔP_{\max} and ΔP_{\min} indicated a higher value for the latter parameter. It was indicated that the imprecise P wave dispersion value correlated most significantly with the maximal P wave duration, which was measured in a similar way. In contrast with the imprecise measurement method, the minimal and maximal durations of the P waves, being measured accurately, were almost identical. Using precise methodology, the P wave dispersion reaches negligible values and tends to zero. The measurements of the P wave have to be precise to assure the highest scientific and medical sincerity. The highest clinical value is related to the P wave duration.

Keywords

P wave duration; P wave dispersion; Total atrial activation time

1. Introduction

The electrical activity of the working myocardium is measurable and can be graphically represented by a 12-lead electrocardiogram. In this form of recording, the electrical signal is recorded by 10 electrodes, which form 6 limb leads: 3 bipolar, 3 unipolar and 6 unipolar precordial [1, 2]. Each limb lead records the flow of electric current in the frontal plane and the precordial leads in the horizontal plane. The polarity of either bipolar or unipolar pair of electrodes allows the myocardial depolarization (which is essentially a change in potential from negative to positive), to produce the appro-

priate deflection [3, 4]. The deflection is positive if the momentary current-vector is lined up with the direction of the bipolar lead or is oriented towards the unipolar lead, or is set negatively in the opposite situation. When the current flows perpendicular in relation to the direction of the bipolar lead, or parallel considering the direction of the unipolar lead, the leads do not register any deflection. This happens because there is no chrono-spatial change in the current flow regarding a particular lead [5, 6]. This fact results in the formation of isoelectric fragments of the electrocardiogram. Considering the complexity of the heart muscle structures, this is never the case in practice, however those facts let us understand some detailed phenomena in precise P wave interpretation. For example, the initial and the closing fragments of the electrocardiogram waveforms may appear to be isoelectric, but with the proper amplification the deflection of the line will be visible.

The described phenomenon is consistent with the general properties of current-flow recording: if a given phenomenon has started and is being recorded by some leads, one cannot assume that the phenomenon is not present in the other leads just because the amplitude of the recorded signal is low. For obvious reasons, the described problem more often concerns the electrical activity of the atrium, as the amplitude of the P wave is many times lower and more subtle than the QRS complex, due to the differences in the masses of the atria and ventricles. The described problem was the basis of the incorrect theory of the so-called 'P wave dispersion', introduced in the late 20th century [7]. Despite the critical work on the accuracy of the P wave measurement, which was also raised by the authors of the dispersion concept themselves [8–10], this theory has become established in medicine, leading to the creation of many works that describe this phenomenon based on insufficient accuracy of taking measurements [11–14].

The use of the vector graphics and the electrophysiological system for the measurement of the P wave allowed for a much more accurate assessment [15–17]. In the following study, we want to show that, the problem of inaccuracy in the assessment of P wave duration is a common problem, and is only slightly dependent on the type of patient population with various atrial arrhythmias.

2. Aim

The aim of the study was to assess the duration of the P wave and its indices in a wide, unselected population of patients with common arrhythmias – atrioventricular nodal reentrant tachycardia (AVNRT), typical atrial flutter (AFL) and atrial fibrillation (AF), and to demonstrate the similarities in the inaccuracy of the P wave duration measurement depending on the method used.

3. Material and methods

The study included 186 patients (78M 108F) aged 59.7 ± 12.9 years, under-going various electrophysiological procedures using LabSystem TM Pro EP Recording System (Boston Scientific, Boston, MA, USA). The group was divided into three equally numerous subgroups: AVNRT (62), AFL (62), and AF (62). The electrophysiological procedures included: electrophysiological studies; AV-nodal reentrant tachycardia (AVNRT), atrioventricular reentrant tachycardia (AVRT), atrial flutter (AFL). The only inclusion criterion was the presence of sinus rhythm and the quality of the ECG tracings, which allowed us to measure the sinus P wave duration. All patients were in sinus rhythm at the time of recording. The P wave duration was measured in all leads twice: first time at the paper speed of 25 mm/s, enhancement $8\times$ (basic measurement Fig. 1A), and second time at the paper speed of 200 mm/s, enhancement $64\text{--}256\times$ (Fig. 1B). The P wave dispersion was calculated, as the difference between P_{max} and P_{min} in different leads for each measurement setting. The P wave measurements for every tracing were repeated 5 times for accuracy by 2 independent researches, who were unaware of each other's results and who were blinded to clinical data. The final value presented for each patient was their average. The study was approved by the local Bioethical Committee at Wroclaw Medical University, Poland. In order to avoid the above-mentioned measurement inaccuracies, we decided to use an electrophysiological system to have an insight into every millisecond of recorded pulse (Fig. 1).

4. Results

The clinical baseline characteristics of the studied patients and the results of measurements of the P wave duration are presented in Table 1.

Table 2 presents a summary of the measurement data concerning the duration and dispersion of the P wave. Below we present the result of the Wilcoxon signed-rank test for pairs of observations regarding the dispersion of the P wave measured by the accurate (AM) and inaccurate (IM) meth-

ods. The difference between the P wave dispersion determined from the measurement results by the imprecise and accurate method is highly significant (46.6 ms vs. 4.6 ms; $p < 0.001$; Fig. 2).

The coefficients of variation ($CV\% = SD / \text{Mean} \times 100$) estimated on the basis of imprecise and accurate P wave duration measurements differ significantly (Fig. 3). Also the ranges (range = Max–Min) for CV% in the inaccurate method are much larger than in the accurate method. Fig. 4 presents the comparison of the coefficients of variability regarding accurate and inaccurate method of the P wave measurements.

The correlation between the P wave dispersion and the maximum and minimum time of the P wave duration are presented in Table 3.

The differences between imprecise and precise methodology of the P wave duration measurements are presented in Table 4.

The differences between the P wave durations in men and women, using inaccurate and accurate methods are presented in Table 5.

There was no statistically significant relationship between the results of the P wave duration measurement (ms) and the sex of the patients ($p > 0.05$).

Based on the above analysis, we can draw conclusions that the variability in the measurement of the maximum and minimum P wave durations is much greater with the imprecise ($50 \text{ mm/s } 8\times$) measurement method than with the precise ($64\text{--}256\times$, 200 mm/s). In the case of measuring the dispersion of the P wave alone, the coefficient of variation between the two methods is incomparably greater for imprecise measurements. The dispersion of the P wave duration defined in the less accurate method depends on the values of both P_{max} and P_{min} , while in the accurate method there is no such relationship and the dispersion value itself is way smaller. There was no statistically significant relationship between the results of the P wave duration measurement (ms) and the sex of the patients. The groups were homogeneous in terms of gender structure, but there is a statistically significant difference in age: patients in the AVNRT group were younger than AF patients by an average of 8 years.

5. Discussion

The most important and the most spectacular achievement of our research is the proof, that the duration of the P wave dispersion is clearly dependent on the technology used to calculate it. Taking a closer look at the details of the following topic, it's reasonable to begin with basic electrocardiographic rule. All electrocardiographic events are registered in all ECG leads in the same time [18]. This is logical, because the leads should be perceived as the different perspectives, from which the very same impulse is being observed. Objectively it is impossible that the very same impulse begins or ends in different moments in different leads. Therefore, it is simply against the basic physical rules describing the relations of space and time. Despite this fact, in 1998 Dilaveris

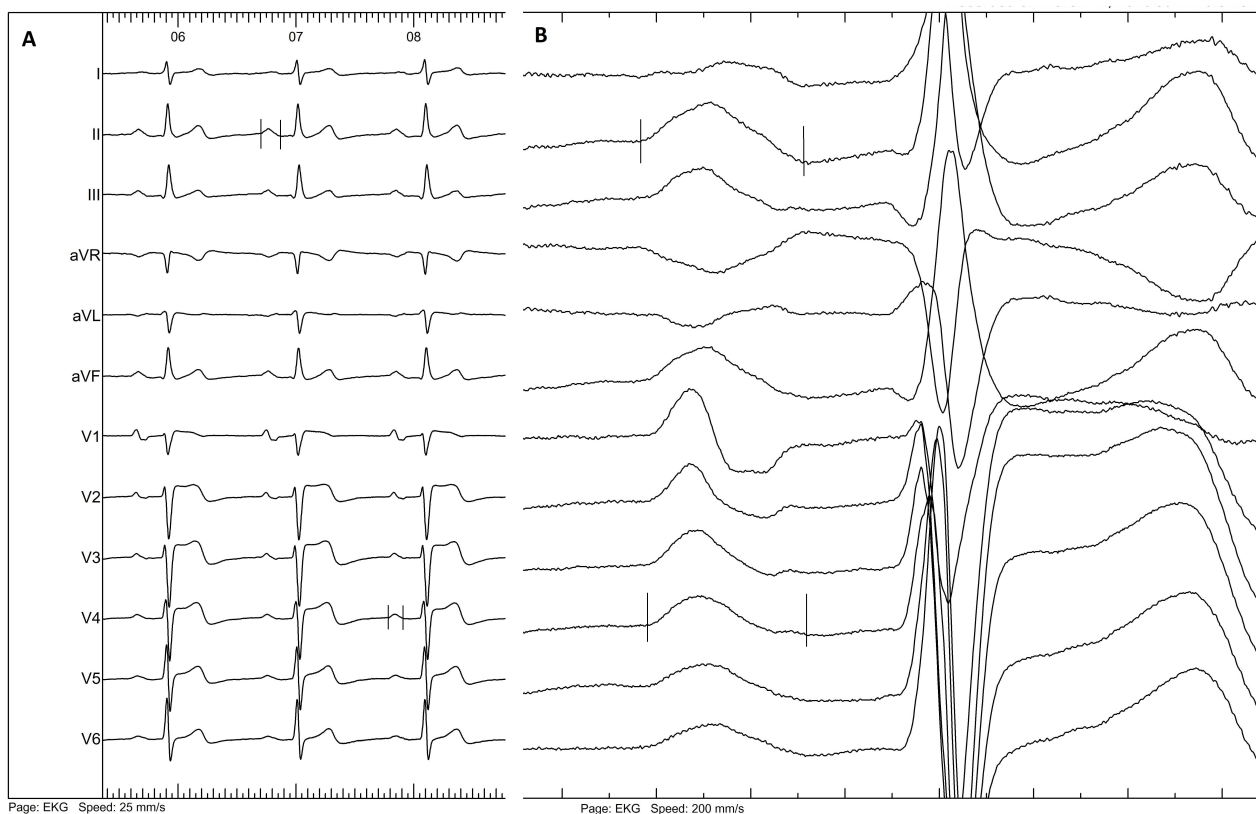


Fig. 1. P wave duration measured inaccurate and accurate and the visual changes in presented electrocardiograms. (A) The measurements taken at the paper speed of 25 mm/s, enhancement 8×; P wave duration: II 148 ms, V4 126 ms. (B) The accurate measurements taken at the speed of 200 mm/s, enhancement 64× – by the means of vector graphics, P wave duration: II 178 ms, V4 173 ms.

Table 1. Clinical and demographic characteristics of the patients in the three study groups.

Variable	Group						<i>p</i> -value
	AVNRT, N = 62		AFL, N = 62		AF, N = 62		
	n	%	n	%	n	%	
Sex							0.167
Women	42	67.7%	34	54.8%	32	51.6%	
Men	20	32.3%	28	45.2%	30	48.4%	
Comorbidities							<0.05
HT	37	59.7%	44	70.1%	46	74.2%	
DM	5	8.1%	11	17.7%	13	21.0%	
CKD	4	6.5%	6	9.7%	5	8.1%	
IHD	6	9.7%	12	19.4%	11	17.7%	
HF	4	6.5%	7	11.3%	6	9.7%	
Age, years							<0.001
Mean ± SD	54.2 ± 15.5		60.4 ± 13.1		64.5 ± 10.2		
Me [Q1; Q3]	58 [45; 64]		63 [53; 70]		66 [58; 70]		
Min to Max	21 to 80		23 to 90		39 to 87		

DM, diabetes mellitus; CKD, chronic kidney disease; IHD, ischemic heart disease; HF, heart failure, HT, hypertension; AVNRT, atrioventricular re-entry nodal tachycardia; AFL, atrial flutter; AF, atrial fibrillation; SD, standard deviation; Me [Q1; Q3]: median I quartile range.

Table 2. The results of duration measurements of the P wave by the imprecise (IM) and precise (AM) methods.

Statistics	Inaccurate method	Accurate method	p-value
P_{max} (ms)			<0.001
Mean \pm SD	126.4 \pm 27.2	143.5 \pm 24.1	
Me [Q1; Q3]	122 [100; 145]	141 [126; 162]	
Min to Max	37 to 180	84 to 208	
P_{min} (ms)			<0.001
Mean \pm SD	77.4 \pm 27.5	138.9 \pm 23.8	
Me [Q1; Q3]	76 [56; 100]	135 [121; 158]	
Min to Max	23 to 138	84 to 201	
P_{dysp} (ms)			<0.001
Mean \pm SD	46.6 \pm 16.7	4.6 \pm 2.8	
Me [Q1; Q3]	44 [35; 59]	4 [3; 7]	
Min to Max	14 to 124	-4 to 11	
$SD_{P_{max}}$ (ms)			<0.001
Mean \pm SD	6.9 \pm 5.8	5.5 \pm 5.8	
Me [Q1; Q3]	6 [3; 9]	4 [2; 7]	
Min to Max	0 to 35	0 to 34	
$V_{P_{max}}$ (%)			<0.001
Mean \pm SD	6.1 \pm 5.8	15.1 \pm 2.6	
Me [Q1; Q3]	4 [2; 8]	15 [13; 17]	
Min to Max	0 to 37	10 to 25	
$SD_{P_{min}}$ (ms)			<0.001
Mean \pm SD	9.5 \pm 8.2	5.6 \pm 5.9	
Me [Q1; Q3]	7 [4; 14]	4 [2; 7]	
Min to Max	0 to 49	0 to 37	
$V_{P_{min}}$ (%)			<0.001
Mean \pm SD	14.2 \pm 13.9	4.1 \pm 4.5	
Me [Q1; Q3]	9 [5; 17]	3 [1; 3]	
Min to Max	0 to 81	0 to 28	

Ms, milliseconds; SD, standard deviation; V, variance; Me [Q1; Q3], median I quartile range.

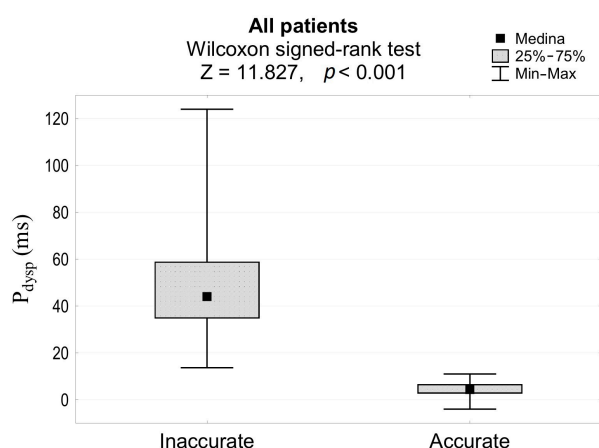


Fig. 2. P wave duration dispersion measured inaccurate and accurate and the result of the signed rank test.

et al. [7] introduced the P wave dispersion which was defined as the difference between the longest and the shortest P waves in two different leads. The authors calculated the P wave duration, with the use of ruler, magnifying glass and

the ECG millimeter-paper print, at the speed of 50 mm/s and 1 mV/cm gain. The study group included 60 patients with paroxysmal AF, and the control group included 40 healthy patients with the similar profile. The maximal P wave duration of 110 ms and the dispersion of 40 ms were the differential factors between the study and control group with the positive prediction of 89%. In the study group the dispersion was 49+/- ms and in the control one - 28+/- ms, which was statistically relevant. As a result, the definition of P wave dispersion gained popularity in scientific world, and the methodology of research has been repeated by many followers ever since. For example, Dogan *et al.* [19], acquired the P wave dispersion of 53.2 \pm 3.9 ms vs. 40.3 \pm 4.7 ms in his work on the P wave in AF and sinus rhythm. Similarly, Akcay in 2018 in his work about influence of moderate altitudes on electrocardiographic measurements, measured the P wave dispersion of 28.6 \pm 10.2 ms at moderate altitude and 27.4 \pm 9 ms at sea level [20]. The results of the latter research were acquired after having measured the difference between P_{max} and P_{min} in the same lead, which makes the methodology and its interpretation faulty. The multiplicity of different approaches prompted our team to publish an overview of researches on methodologies measurement acquisition. It was stated, that in case of manual measurements at the speed of 25-50 mm/s the P wave dispersion fluctuated at 40 ms. The precision of measurement wasn't improved after using a magnifying glass for zoom (raster graphic). What's interesting, two years after the P wave dispersion theory had been introduced, Yamada *et al.* [21], supported his study with automatic software, which resulted in the P wave dispersion of 26.6 +/- 9.5 ms (study group) and 14.8 +/- 6.7 ms (control group). The values were significantly lower than the results presented by Dilaveris, but still far from the numbers presented in our work: P_{dysp} : 4.0 \pm 3.1 ms (AVNRT); 4.4 \pm 2.7 ms (AFL); 4.4 \pm 2.7 ms (AF) (Table 3). Referring to the enumerated examples, the differences came directly from improving the precision of manual measurement, and from the sensitivity of the algorithms used by Yamada, which made our team draw certain conclusions.

The precursor of the new methodology was the team of Zimmer *et al.* [22] who presented their results at the Europace conference in 2015. The authors took the measurements for the first time at the settings: 50 mm/s, 8x; and the other time, more precisely: 200 mm/s, 128-256x. The results in the less precise measurements revealed dispersion at the level of 45.14 ms, whereas the more accurate methodology resulted in 1.24 ms, i.e., disappeared in total. The results indicated the direct high correlation P_{max}/P_{dysp} , meaning dispersion is not the individual, independent parameter. The confirmation of this discovery was the research that was published in 2020 in Advances in Clinical and Experimental Medicine [17]. 104 patients were analyzed and qualified for various electrophysiological procedures. Using the methodology of Zimmer *et al.* [22], the P wave dispersion acquired by inaccurate method was: 44.1 \pm 16.8 ms, and 2.8 \pm 3.4 ms

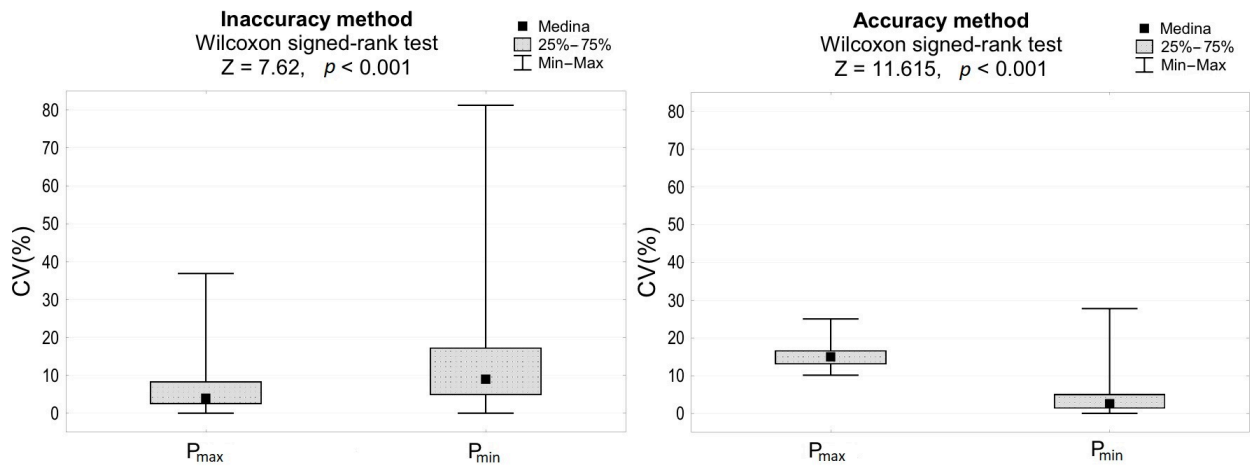


Fig. 3. Comparison of the variability coefficients of the maximum and minimum P wave durations measured with inaccurate and accurate method and the result of the signed rank test.

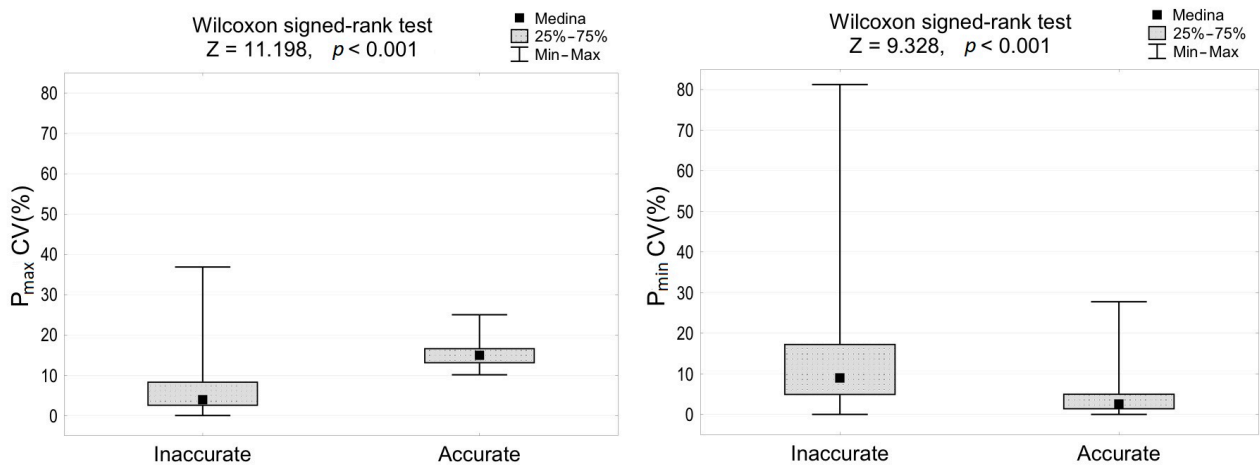


Fig. 4. Comparison of the coefficients of variability of the results of measurements made with inaccurate and accurate method of the maximum and minimum durations of the P wave and the results of the signed rank test.

Table 3. The values of Pearson's correlation coefficients between the dispersion of the P wave duration and the maximum and minimum time in the entire study population and in groups of patients with different health status.

Method	Parameter	All, N = 186	AVNRT, N = 62	AFL, N = 62	AF, N = 62
Inaccurate	P_{max}	0.292	0.167	0.390	0.266
	P_{min}	-0.319	-0.519	-0.117	-0.461
Accurate	P_{max}	0.133	0.126	0.095	-0.052
	P_{min}	0.018	-0.041	-0.026	-0.159

Correlation coefficients other than zero at the level of $p < 0.05$ were marked.

N, number of patients; AVNRT, atrioventricular nodal re-entry tachycardia; AFL, atrial flutter; AF, atrial fibrillation.

($p < 0.0001$) by precise method. The correlation between the precise P_{max} and P_{min} was almost 1.0 ($r = 0.987$, $p < 0.05$). This means that after improving the measurement precision, the difference between P wave duration in separate leads disappears and the dispersion drops approx. to zero (absolute zero is impossible to reach due to artifacts).

The described results were confirmed by Puerta *et al.* [23], who noticed and focused on the gaps in Dilaveris's theory of heterogeneous, non-homogeneous signal spread, which was the initial explanation of the P wave dispersion phenomenon. Puerta enrolled 153 randomized patients for electrophysiological procedures in his study. In order to verify the method-

Table 4. Results of measurements of P wave duration by imprecise (IM) and accurate (AM) methods in three groups of patients.

Group: AVNRT	Inaccurate method	Accurate method	p-value
	N = 62	N = 62	
P_{max} (ms)			<0.001
Mean \pm SD	107.2 \pm 20.2	126.6 \pm 18.4	
Me [Q1; Q3]	109 [96; 120]	125 [113; 134]	
Min to Max	37 to 168	84 to 179	
P_{min} (ms)			<0.001
Mean \pm SD	62.9 \pm 23.3	122.6 \pm 18.2	
Me [Q1; Q3]	59 [47; 74]	119 [111; 131]	
Min to Max	23 to 117	84 to 176	
P_{dysp} (ms)			<0.001
Mean \pm SD	44.4 \pm 15.5	4.0 \pm 3.1	
Me [Q1; Q3]	44 [34; 56]	4 [1; 7]	
Min to Max	14 to 73	-2 to 10	
Group: AFL	N = 62	N = 62	
P_{max} (ms)			<0.001
Mean \pm SD	130.9 \pm 28.0	150.8 \pm 22.1	
Me [Q1; Q3]	135 [109; 153]	153 [133; 170]	
Min to Max	62 to 179	98 to 195	
P_{min} (ms)			<0.001
Mean \pm SD	87.6 \pm 26.0	146.4 \pm 22.0	
Me [Q1; Q3]	92 [67; 111]	149 [129; 164]	
Min to Max	34 to 138	94 to 184	
P_{dysp} (ms)			<0.001
Mean \pm SD	43.3 \pm 13.9	4.4 \pm 2.7	
Me [Q1; Q3]	40 [33; 53]	4 [3; 6]	
Min to Max	14 to 70	-4 to 11	
Group: AF	N = 62	N = 62	
P_{max} (ms)			<0.001
Mean \pm SD	133.9 \pm 24.9	153.0 \pm 22.2	
Me [Q1; Q3]	134 [122; 149]	154 [134; 169]	
Min to Max	80 to 180	109 to 208	
P_{min} (ms)			<0.001
Mean \pm SD	81.7 \pm 27.0	147.6 \pm 22.4	
Me [Q1; Q3]	82 [60; 103]	152 [128; 164]	
Min to Max	29 to 137	102 to 201	
P_{dysp} (ms)			<0.001
Mean \pm SD	43.3 \pm 13.9	4.4 \pm 2.7	
Me [Q1; Q3]	40 [33; 53]	4 [3; 6]	
Min to Max	14 to 70	-4 to 11	

SD, standard deviation; Me [Q1; Q3], median I quartile range; AVNRT, atrioventricular re-entry nodal tachycardia; AFL, atrial flutter; AF, atrial fibrillation.

ology described by Zimmer *et al.* [22], the authors measured the P wave duration twice: first at: 20 mm/mV; 50 mm/s, 8 \times , and the second time at 200 mm/s, 125–256 \times . With less accurate measurement, the P wave dispersion was on average 48 ms (36–54 ms), and with the precise measurement it dropped to 4 ms (0–10 ms), $p < 0.001$. The authors also compared the morphology of the P waves, recording them at different locations of heart. After manual determination of the signal resultant vector, the researchers found that in

most cases the resultant stimulation axis corresponded with the lead in which P_{max} is registered. In the same time P_{min} is usually recorded in a lead perpendicular to the designated axis in the hexaxial system. The researchers concluded however, the P wave dispersion couldn't be fully explained by the vector theory, although it must be closer to the truth than the local theory. Surprisingly, despite the fact the dispersion dropped to 4 ms (0–10 ms) with precise methodology, Puerta is not convinced that the phenomenon of the P wave dispersion does not exist. This says a lot about the extent to which this theory was rooted in the minds of researchers over last 24 years.

Discussing the precision of the P wave measurement, it is worth focusing on details. For example, the thickness of the isoelectric line itself in the printed ECG averagely equals one third of a millimeter (excluding the R peak in QRS complex), and this thickness may correspond to about 6–7 ms. The isoelectric line marks the beginning and end of the P wave, so the measurement of the segment between the beginning and end with a ruler creates the possibility of falsifying the result by about 14 ms. Another problem is the determination of the objective beginning and end of the P wave. Usually, there is no specific cut-off point at which one should start the measurement. The rise of the isoelectric line, is smooth and often accompanied by line tremors, so-called artifacts. They appear due to the electrical resistance at the boundaries of the electrode-gel-skin mediums, and/or due to the minimal recorded electrical activity of human muscles [24, 25]. In order to avoid the above-mentioned measurement inaccuracies, we decided to use an electrophysiological system to have an insight into every millisecond of recorded pulse. It should be added that, by using the vector graphic, the electrophysiologic software allowed for the zoom of the ECG without any quality loss of the record. Using the electrophysiological system, the researchers were able to analyze the record at the rate of 1 px/1 ms using a 4K TV as the screen. It should be remembered that even the slightest hand tremor can disturb the measurement by a few milliseconds, with such settings [26]. The scale of error with less precise methodology is incomparable. For comparison—Dilaveris *et al.* [7] used a magnifying glass in their research, which means that all inaccuracies, artifacts and averages of the ECG recording at the parameters of 50 mm/s, 8 \times were enlarged on the basis of raster graphics, i.e., they were not corrected, but remained in the same initial form, only enlarged. Therefore, each measurement was bound at the outset, to be erroneous, which was related to specific recording and printing parameters. In the studies of Dilaveris *et al.* [7], it was determined that the P wave dispersion of 40 ms is a predictor of atrial fibrillation recurrence. In our research, the dispersion was 4 ms on average, which corresponds to 4 pixels on taking the measurement. In addition, with structurally damaged atria, the P wave is naturally prolonged and flattened, which makes it difficult to determine its beginning and end [27–29]. Therefore, it is common that the flattened part of the wave can be interpreted as an isoelec-

Table 5. P wave durations measured in women and men using inaccurate (IM) and accurate methods and the results of significance tests (Mann-Whitney U).

Group	P (ms)	Women, N = 108	Men, N = 78	p-value
Inaccurate	P_{disp}	46.5 (35.2–59.3)	42.4 (34.3–56.0)	0.515
	P_{max}	112 (100–143)	129 (108–146)	0.213
	P_{min}	70 (54–100)	80 (60–103)	0.143
Accurate	P_{disp}	4.3 (2.5–6.0)	5.1 (3.0–7.0)	0.109
	P_{max}	134 (121–162)	145 (130–162)	0.122
	P_{min}	130 (116–158)	141 (126–158)	0.174

P, P wave duration; ms, milliseconds; N, number of patients.

tric line after averaging or reading with less precise parameters (25–50 mm/s, $8\times$). This fact results in “self-hiding” of more advanced changes in the P wave in ECG recording. We supported this observation in the research published by our team, in which we described the analysis of 150 patients [30]. The duration of the P wave, assessed in three equal groups: AVNRT, AFL, AF, at 50 mm/s, $16\times$, was respectively: 78.2 ± 10.1 ms; 74.3 ± 11.8 ms; 98.5 ± 21.6 ms. After changing to 200 mm/s, $128\text{--}256\times$ the results were 121.2 ± 15.2 ms; 123 ± 22.2 ms; 141.1 ± 22.8 ms. It is easy to see that with the inaccurate measurement method, the duration of the P wave seemed shorter than it actually was. After improving the precision, time was significantly longer, which more objectively reflected the disturbances in atrial conduction, especially in AF. The accuracy of measurements depends only slightly on the type of arrhythmia (Table 4). This example shows how the methodology of electrocardiographic measurements can objectify the diagnostic process and be useful in clinical practice on a daily basis.

Despite the accuracy, the most precise manual measurements of the P wave duration still seem to be an insufficient proof against the P wave dispersion theory. The main arguments against precise manual methodology are the subjectivity of measurement, and imperfection of a human eye while assessing the duration. In order to oppose these arguments, our team decided to develop an automatic, specially calibrated algorithm which analyses every millisecond of the recording as objectively as it is possible. We drew our inspiration from the algorithm used by Yamada in his research in 1999, who revealed spectacular results two years after the concept of the P wave dispersion had been introduced. Our algorithm called APPA (“Automatic Precise P wave Assessment”) was designed with help of an experienced professional software developer, who was priorly unfamiliar with the P wave measurements issues. The technology is directly based on the automatic analysis of vector graphics, simultaneously comparing and contrasting data from all 12 ECG leads. The automatic assessment is bound to maintain the repeatability of obtaining the results which will make the results more reliable. With this approach, the suggestion of subjectivity will be no longer adequate. We are under the process of testing the software and are planning to publish our first results by the end of October 2021.

The issues of P wave morphology and duration remains a living topic for research. Technological development allows for accurate measurements, but the theory of P wave dispersion is still deeply rooted in the scientific environment. The determination of total atrial activation time and the assessment of the P wave profile seem to be a promising direction of research in the future. Advanced analysis of these variables is bound to increase the chance of determining a new parameter for predicting recurrent atrial fibrillation in clinical practice.

6. Conclusions

- (1) P wave dispersion reach negligible values tending to zero, after increasing the precision of measurement.
- (2) Structural destruction of the atria results in “self-hiding” of the actual duration of the P wave in ECG. In clinical practice, this may contribute to an incorrect assessment of the degree of atrial destruction.

Author contributions

JZ and JG designed the research study. JZ, GZ, P-SW performed the research. JR provided help and access to all data in Cath lab systems. AS and JG analyzed the data. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

Ethics approval and consent to participate

All data collected in the study were based on anonymous ECG recordings saved in electrophysiology system in the process of carrying out different procedures in Cath labs. The subjects gave their informed consent for anonymized data analysis for the scientific purpose. The study was conducted in accordance with the Declaration of Helsinki, and approved by the local Ethics Committee (approval number: KB 813/2019).

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Conflict of interest

The authors declare no conflict of interest.

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