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Common source of miscalculation and misclassification of P-wave negativity and P-wave terminal force in lead V1

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ABSTRACT

Background: P-wave terminal force (PTF) > 4000 ms·μV and deep terminal negativity (DTN) are ECG markers of left atrial abnormality associated with both atrial fibrillation and stroke. When the precordial lead V1 is placed higher than the correct position in the fourth intercostal space, it may cause increased PTF and DTN. Several studies have documented that electrode misplacement, especially high placement, is common. The influence of electrode misplacement on these novel ECG markers has not previously been quantified.
Objective: The objective was to assess the influence of electrode misplacement on PTF and DTN.
Method: 12-Lead ECGs were recorded in 29 healthy volunteers from the Department of Cardiology at the Copenhagen University Hospital of Bispebjerg. The precordial electrode V1 was placed in the fourth, third and second intercostal space, giving a total of 3 ECGs per subject. Continuous variables were compared using Dunnett's post-hoc test and categorical variables were compared using Fischer's exact test.
Results: High placement of V1 electrodes resulted in a more than three-fold increase of PTF (IC4 = 2267 ms·μV, IC2 = 7996 ms·μV, p-value < 0.001). There was a similar increase of DTN (IC4 = 0%, IC2 = 28%, p-value < 0.001). P-wave area and amplitude of the negative deflection increased, and P-wave area and amplitude of the positive deflection decreased. The P-wave shape changed from being predominantly positive or biphasic in IC4 to 90% negative in IC2. The PR-duration and P-wave duration were not altered by electrode placement.
Conclusion: High electrode placement results in significant alteration of PTF and DTN in lead V1.

Introduction

P-wave terminal force (PTF) is slowly gaining momentum in identifying patients at risk of developing atrial fibrillation (AF) [1] and stroke [2]. PTF is specific to precordial lead V1 and is defined as the duration multiplied by the amplitude of the negative part of a biphasic p-wave, measured in μV·ms. Deep terminal negativity in V1 (DTN), defined as the amplitude of the negative part of a biphasic P-wave in V1 above 100 μV or the height of 1 small ECG grid square, has been argued to be a comparable measure to PTF and to be an easier and faster way to gain the same information as is possible from PTF [3,4]. The term PTF was first coined by Morris in 1964 [5]. When the P-wave is biphasic in V1 the first positive deflection is a representation of the depolarization of the right atrium and the second negative deflection is a representation of the depolarization of the left atrium [6]. When the left atrial mass or chamber size increases, there is an increase in the P-wave amplitudes and durations. As the left atrium is generally activated late in the P-wave, an abnormality would theoretically lead to an increase in the terminal portion. An increased terminal negative deflection is therefore suggested as a marker for left atrial abnormality. A PTF over 4000 μV·ms or a DTN above 100 μV are deemed to be pathological and are hypothesized to be markers of left atrial abnormalities such as fibrosis and dilatation [7], both of which are known risk factors for developing both AF and stroke [8].

Several studies have found associations between PTF or DTN and later development of both AF and stroke [1,2,4,9]. However, while abnormal PTF and DTN may be signs of left atrial abnormalities, they can also be signs of high electrode placement [10–12]. It has been documented in several studies that misplacement, especially high placement, of precordial electrodes is common in clinical settings [13,14]. Furthermore, studies have shown that especially leads V1 and V2 are commonly subject to high placement [15]. When V1 and V2 are misplaced, the remaining precordial electrodes will typically also be misplaced. This may affect the morphology of the ECG and can lead to

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misinterpretation or diagnostic error because of morphological changes [16], including false abnormal findings such as brugada pattern or other findings that could indicate ischemia [17]. Increased negativity of the P-wave in V1 and V2 is one such morphological change [18]. This is problematic if we are to use PTF or DTN as tools to identify patients at risk of AF or stroke.

The influence of this common electrode misplacement on these novel atrial ECG markers has not previously been quantified. Thus, we designed a study testing intercostal placement of the precordial V1 electrode, to assess the influence of electrode misplacement on PTF and DTN.

Methods

Subjects were healthy volunteers, with no known health conditions and no symptoms of cardiovascular disease, included from the Department of Cardiology at Copenhagen University Hospital. Volunteers all reported engaging in mild to moderate amounts of exercise and none of the volunteers practiced sport at an elite level. All subjects underwent 12-lead ECG recording. The precordial electrodes V1 and V2 were placed in the fourth intercostal space, which is the standard electrode placement [6,16], and subsequently in the third and second intercostal spaces, giving a total of 3 ECGs per subject. The remaining precordial electrodes (V3–V6) were then placed, according to the V1 and V2, electrodes one intercostal space down (see Fig. 1). Limb lead electrodes were not moved. The study was approved by the local ethics committee and all volunteers provided an informed consent.

Electrocardiogram recordings

ECGs were digitally taken using a hardware filter (0.15–150 Hz) and stored in a MUSE Cardiology Information System (GE Healthcare, Wauwatosa, Wisconsin, USA) and later processed using version 21 of the Marquette 12SL algorithm with automatic calculation of fiducial points and amplitude/area calculation. ECGs were then manually reviewed by one investigator. ECGs of poor quality (e.g. missing leads or baseline drift) or ECGs with rhythms other than sinus rhythm (e.g. atrial fibrillation) were excluded.

The following parameters were extracted from the MUSE system: P-wave duration in V1, P-wave duration, P-wave amplitude and P-wave area of the positive and negative portion in V1. PTF was calculated based on the duration multiplied by the amplitude of the terminal portion of the P-wave in V1.

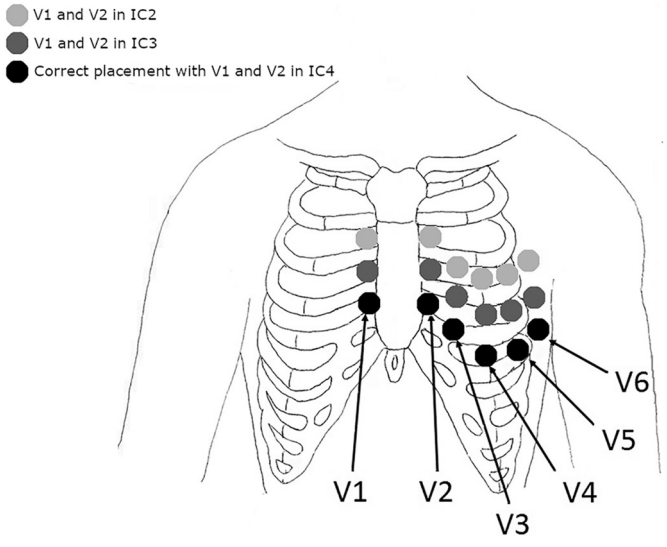

Fig. 1. Precordial electrode placement and misplacement.

Statistics

Statistics were conducted using R [19]. Continuous variables were compared with an ANOVA using Dunnett's post-hoc tests. Categorical variables were compared using Fischer's exact test. Age, weight and height were tested for significant influence as covariates.

Results

The study included 31 subjects, of these 2 subjects were excluded because of non-sinus rhythms, leaving 29 subjects for analysis. See Table 1 for baseline characteristics. There was no influence of covariates on ECG markers. When the V1 electrode was moved from IC4 to IC3 and IC2, there was over a three-fold increase in the average PTF in this group from electrode placement in IC4 to IC2. DTN increased similarly. The percentage of subjects with a pathological PTF or DTN also increased by more than a factor of three. The P-wave amplitude and area of the positive deflection decreased, whereas the negative deflection (left atrial component) increased. All mentioned changes were statistically significant (Table 2). The P-wave duration and PR-duration were not altered by electrode placement.

The P-wave also changed its shape from being predominantly positive or biphasic in IC4 to predominantly negative in IC2, as shown in Table 2. Fig. 2 demonstrates these morphological changes in one subject. Note also the increased negativity of the T-wave and the rSr′ pattern that arises when the electrodes are highly placed.

Discussion

This study demonstrates that moving the V1 precordial electrode from IC4 to IC3 and IC2 caused increased negativity of the p-wave. The risk of misclassification of PTF and DTN because of electrode misplacement is clear even in this small study. Clearly, it is problematic that misplacement of electrodes can cause misclassification, if PTF or DTN are to be used in a clinical setting.

Although an increased terminal negative deflection is suggested as a marker for left atrial abnormality, this study shows that when the electrodes look at the heart from a more cranial angle the first positive deflection decreases and the terminal portion increases. It is not possible to differentiate with certainty whether the cause of the increase of terminal force and negativity is due to left atrial abnormality or due to the angle at which the electrode is looking at the atria. Therefore, it can be difficult to establish whether an abnormal PTF is pathological or merely an artefact.

This study is in accordance with other studies that show that high placement of V1 electrodes increases the negative component of the P-wave in V1 [20]. This study is also consistent with other studies, suggesting that a fully negative P-wave in V1 can be a sign of high electrode placement [10,11]. The rSr′ pattern may also be a sign of high placement [17], and is demonstrated in this study by Fig. 2.

The increased P-wave negativity that occurs with high electrode placement makes P-wave indices measured in V1, particularly those involving measures of amplitude, susceptible to miscalculation and misclassification. PTF or DTN are measures largely or completely based on amplitude. Furthermore, studies have shown that erroneously placed electrodes are, in fact, common practice in busy ERs and hospital

Table 1
Baseline characteristics, 29 healthy volunteers.

N	29
Male (%)	12 (41%)
Age (IQR)	32 years (27, 38)
BMI	23.8 (3.2)
Heart rate (SD)	66 (12)
Systolic blood pressure (SD)	120 (10)
Diastolic blood pressure (SD)	71 (8)

Table 2
P-wave characteristics in V1 based on electrode placement.[a]

		IC4	IC3	IC2	p-Value
N		29	29	29	
PTF, ms·μV		1872 (0, 3696)	4730 (2304, 7830)*	9180 (4704, 11,232)*	<0.001
PTF >4000 ms·μV		21%	59%*	83%*	<0.001
P-wave amplitude, μV (positive deflection)		34 (24, 48)	0 (0, 14)*	0 (0, 0)*	<0.001
P-wave amplitude, μV (negative deflection)		−29 (−48, 0)	−58 (−83, −34)*	−87 (−102, −48)*	<0.001
DTN		0%	15%*	32%*	<0.001
P-wave area, ms·μV (positive deflection)		878 (508, 1405)	0 (0, 351)*	0 (0, 0)*	<0.001
P-wave area, ms·μV (negative deflection)		−3963 (−5290, −2791)	−2421 (−3260, −2791)*	−937 (−1854, 0)*	<0.001
P-wave shape	Positive	9 (31%)	2 (7%)	0 (0%)	<0.001
	Biphasic	17 (59%)	13 (45%)	3 (10%)	
	Negative	3 (10%)	14 (48%)*	26 (90%)*	
P-wave duration, ms		92 ± 26	98 ± 25**	102 ± 12**	0.25
PR-duration, ms		158 ± 24	158 ± 24**	157 ± 25**	0.99

[a] Values are mean ± SD, n (% ± SD), % or median (Q1, Q3).
* p-Value < 0.001 when compared with correct placement in IC4.
** p-Value > 0.05 when compared with correct placement in IC4.

departments, also by highly-trained medical professionals and even by cardiologists [13–15]. This greatly undermines the value of PTF or DTN as prognostic tools in a clinical setting. As electrode misplacement is both a common and persistent problem, these are arguably not reliable markers for left atrial abnormality.

On the contrary, although not investigated in this study, limb leads seem to be less susceptible to placement error within the correct limb, and placement error of the electrode within the correct limb does not have as great an influence on the ECG morphology as precordial leads [18]. This would make limb leads more reliable sources for ECG measurements to be used in clinical diagnostics. Interatrial block is measured in the limb leads and is often associated with PTF in case of advanced interatrial block [21]. Interatrial block has been shown to be a marker for later development of AF [22]. A recent study has shown P-wave axis to be associated with stroke and also to improve the prediction of AF-related stroke when added to other CHA_2DS_2-VASc-score variables [23]. P-wave axis is calculated based on the 6 limb leads and interatrial block is calculated based on P-wave duration in limb leads and number of biphasic P-waves in inferior leads (II, III and aVF) [24,25], and therefore interatrial block and P-wave axis have the advantage of not being susceptible to precordial placement error.

Studies have proven that misplacement not only occurs, but is frequent, and this must be taken into consideration when evaluating which tools are useful for clinicians. Furthermore, it is worth mentioning that others have shown poor repeatability for PTF measured at different visits [26] and poor reliability of PTF in ischemic stroke [27]. Other studies have demonstrated that comparing left atrial enlargement assessed by echocardiography and computed tomography with proposed surrogate ECG markers have not shown an association for PTF as a surrogate marker [28–30].

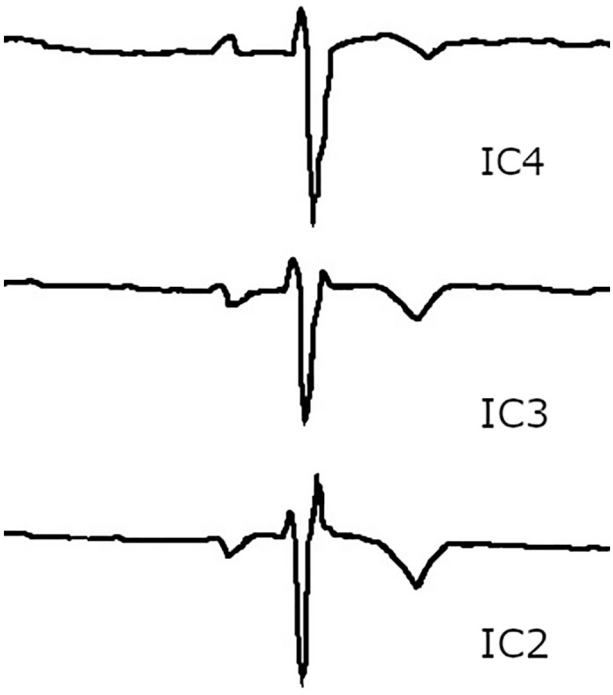

Fig. 2. P-wave shape with different V1 placement in same subject.

Conclusion

High electrode placement results in significantly increased PTF, DTN and overall negativity of the P-wave in lead V1.

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References

[1] German DM, Kabir MM, Dewland TA, Henrikson CA, Tereshchenko LG. Atrial fibrillation predictors: importance of the electrocardiogram. Ann Noninvasive Electrocardiol 2016;21:20–9. https://doi.org/10.1111/anec.12321.
[2] He J, Tse G, Korantzopoulos P, Letsas KP, Ali-Hasan-Al-Saegh S, Kamel H, et al. P-wave indices and risk of ischemic stroke: a systematic review and meta-analysis. Stroke 2017;48:2066–72. https://doi.org/10.1161/STROKEAHA.117.017293.
[3] Tereshchenko LG, Henrikson CA, Sotoodehnia N, Arking DE, Agarwal SK, Siscovick DS, et al. Electrocardiographic deep terminal negativity of the P wave in V1 and risk of sudden cardiac death: the Atherosclerosis Risk in Communities (ARIC) study. J Am Heart Assoc 2014;3:1–11. https://doi.org/10.1161/JAHA.114.001387.
[4] Tereshchenko LG, Shah AJ, Li Y, Soliman EZ. Electrocardiographic deep terminal negativity of the P wave in V1 and risk of mortality: the National Health and Nutrition Examination Survey III. J Cardiovasc Electrophysiol 2014;25:1242–8. https://doi.org/10.1111/jce.12453.
[5] Morris JJ, Estes EH, Whalen RE, Thompson HK, McIntosh HD. P-wave analysis in valvular heart disease. Circulation 1964;29:242–52. https://doi.org/10.1161/01.CIR.29.2.242.
[6] Braunwald E. Electrocardiography. Braunwald's hear. dis. A textb. cardiovasc. med.9th ed. ; 2012. p. 126–67.
[7] Okin PM, Kamel H, Kjeldsen SE, Devereux RB. Electrocardiographic left atrial abnormalities and risk of incident stroke in hypertensive patients with electrocardiographic left ventricular hypertrophy. J Hypertens 2016;34:1831–7. https://doi.org/10.1097/HJH.0000000000000989.
[8] Kirchhof P, Benussi S, Kotecha D, Ahlsson A, Atar D, Casadei B, et al. 2016 ESC Guidelines for the management of atrial fibrillation developed in collaboration with EACTS. Europace 2016;18:1609–78. https://doi.org/10.1093/europace/euw295.
[9] Magnani JW, Zhu L, Lopez F, Pencina MJ, Agarwal SK, Soliman EZ, et al. P-wave indices and atrial fibrillation: cross-cohort assessments from the Framingham Heart Study (FHS) and Atherosclerosis Risk in Communities (ARIC) study. Am Heart J 2015;169:53–61.e1. https://doi.org/10.1016/j.ahj.2014.10.009.
[10] García-Niebla J, Rodríguez-Morales M, Valle-Racero JI, de Luna AB. Negative P wave in V1 is the key to identifying high placement of V1–V2 electrodes in

nonpathological subjects. Am J Med 2012;125:e9-10. https://doi.org/10.1016/j.amjmed.2011.12.024 [author reply e13].
[11] Ilg KJ, Lehmann MH. Importance of recognizing pseudo-septal infarction due to electrocardiographic lead misplacement. Am J Med 2012;125:23–7. https://doi.org/10.1016/j.amjmed.2011.04.023.
[12] Ishikawa K, Yanagisawa A. Influence of an upward shift in the V1 electrode position on the P-terminal force. Angiology 1981;32:485–8. https://doi.org/10.1177/000331978103200705.
[13] Rajaganeshan R, Ludlam CL, Francis DP, Parasramka SV, Sutton R. Accuracy in ECG lead placement among technicians, nurses, general physicians and cardiologists. Int J Clin Pract 2008;62:65–70. https://doi.org/10.1111/j.1742-1241.2007.01390.x.
[14] McCann K, Holdgate A, Mahammad R, Waddington A. Accuracy of ECG electrode placement by emergency department clinicians. Emerg Med Australas 2007;19:442–8. https://doi.org/10.1111/j.1742-6723.2007.01004.x.
[15] Medani SA, Hensey M, Caples N, Owens P. Accuracy in precordial ECG lead placement: improving performance through a peer-led educational intervention. J Electrocardiol 2017;51:50–4. https://doi.org/10.1016/j.jelectrocard.2017.04.018.
[16] Kligfield P, Gettes LS, Bailey JJ, Childers R, Deal BJ, Hancock EW, et al. Recommendations for the standardization and interpretation of the electrocardiogram. J Am Coll Cardiol 2007;49:1109–27. https://doi.org/10.1016/j.jacc.2007.01.024.
[17] Walsh B. Misplacing V1 and V2 can have clinical consequences. Am J Emerg Med 2018;36:865–70. https://doi.org/10.1016/j.ajem.2018.02.006.
[18] Kania M, Rix H, Fereniec M, Zavala-Fernandez H, Janusek D, Mroczka T, et al. The effect of precordial lead displacement on ECG morphology. Med Biol Eng Comput 2014;52:109–19. https://doi.org/10.1007/s11517-013-1115-9.
[19] R Core Team. R: a language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing; 2018 Available from: https://www.R-project.org/ [n.d.].
[20] García-Niebla J. Comparison of P-wave patterns derived from correct and incorrect placement of V1–V2 electrodes. J Cardiovasc Nurs 2009;24:156–61. https://doi.org/10.1097/JCN.0b013e318197aa73.
[21] Chhabra L, Devadoss R, Chaubey VK, Spodick DH. Interatrial block in the modern era. Curr Cardiol Rev 2014;10:181–9.
[22] Skov MW, Ghouse J, Kühl JT, Platonov PG, Graff C, Fuchs A, et al. Risk prediction of atrial fibrillation based on electrocardiographic interatrial block. J Am Heart Assoc 2018;7. https://doi.org/10.1161/JAHA.117.008247.
[23] Maheshwari A, Norby FL, Roetker NS, Soliman EZ, Koene RJ, Rooney MR, et al. Refining prediction of atrial fibrillation-related stroke using the P2-CHA2DS2-VASc score: the Atherosclerosis Risk in Communities (ARIC) study and Multi-Ethnic Study of Atherosclerosis (MESA). Circulation 2018;139:180–91.
[24] Bayés de Luna A, Platonov P, Cosio FG, Cygankiewicz I, Pastore C, Baranowski R, et al. Interatrial blocks. A separate entity from left atrial enlargement: a consensus report. J Electrocardiol 2012;45:445–51. https://doi.org/10.1016/j.jelectrocard.2012.06.029.
[25] Bayés de Luna A, Baranchuk A, Alberto Escobar Robledo L, Massó van Roessel A, Martínez-Sellés M. Diagnosis of interatrial block. J Geriatr Cardiol 2017;14:161–5 [doi:10.11909].
[26] Snyder ML, Soliman EZ, Whitsel EA, Gellert KS, Heiss G. Short-term repeatability of electrocardiographic P wave indices and PR interval. J Electrocardiol 2014;47:257–63. https://doi.org/10.1016/j.jelectrocard.2013.11.007.
[27] Sajeev JK, Koshy AN, Dewey H, Kalman JM, Bhatia M, Roberts L, et al. Poor reliability of P-wave terminal force V1 in ischemic stroke. J Electrocardiol 2019;52:47–52. https://doi.org/10.1016/j.jelectrocard.2018.11.007.
[28] Batra MK, Khan A, Farooq F, Masood T, Karim M. Assessment of electrocardiographic criteria of left atrial enlargement. Asian Cardiovasc Thorac Ann 2018;26:273–6. https://doi.org/10.1177/0218492318768131.
[29] Petersson R, Berge HM, Gjerdalen GF, Carlson J, Holmqvist F, Steine K, et al. P-Wave Morphology is Unaffected by Atrial size: a Study in healthy Athletes. Ann Noninvasive Electrocardiol 2014;19:366–73. https://doi.org/10.1111/anec.12132.
[30] Truong QA, Charipar EM, Ptaszek LM, Taylor C, Fontes JD, Kriegel M, et al. Usefulness of electrocardiographic parameters as compared with computed tomography measures of left atrial volume enlargement: from the ROMICAT trial. J Electrocardiol 2011;44:257–64. https://doi.org/10.1016/j.jelectrocard.2010.04.011.