ORIGINAL ARTICLE

Significance of a negative sinus P wave in lead V_2 of the clinical electrocardiogram

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Background: A negative sinus P wave in lead V_2 (NPV₂) of the electrocardiogram (ECG) is rare when leads are positioned correctly. This study was undertaken to clarify the significance of an unusually high incidence of this anomaly found in ECGs at my institution.

Methods: One thousand four hundred thirty-five ECGs were randomly selected to determine the incidence and gender frequency in tracings showing positive (PPV₂), and biphasic (BPV₂) P waves in V_2 , as well as NPV₂. To those cases with NPV₂, 84 cases with that anomaly from earlier archived ECGs were added to give a larger group for analysis. Medical records were reviewed for clinical details and other archived ECGs.

Results: PPV₂, BPV₂, and NPV₂ were found in 1,216 (84.5%), 150 (10.5%), and 69 cases (4.8%), respectively. Cases with NPV₂ were more likely to be female (46 of 69 or 67.7%) than were those with either PPV₂ (500 of 1,216 or 41.1%; $p < .001$), or BPV₂ (71 of 150 or 47.3%; $p < .01$). NPV₂ was commonly associated with ECG findings of left atrial abnormality (LAA), septal myocardial infarction, or a ventricular repolarization abnormality, but when multiple ECGs were available in these cases, such abnormalities were usually absent when there was either PPV₂ or BPV₂.

Conclusions: With correct precordial lead placement, NPV₂ is rare and BPV₂ is also uncommon, and their presence should alert one to the probability of high placement of V_1 and V_2 , which can produce ECGs that mimic LAA, septal infarction, and ventricular repolarization abnormality.

KEYWORDS

electrocardiography, lead placement error, negative P wave in V_2

1 | INTRODUCTION

In the clinical 12-lead electrocardiogram (ECG), when precordial electrodes are correctly positioned, P waves originating in the sinus node will usually be upright in lead V_2 , rarely biphasic, and almost never completely negative (García-Niebla, 2009; Mirvis, 1980; Surawicz & Knilans, 2001). If biphasic, the P wave should have an initial positivity as initial right atrial depolarization proceeds anteriorly as well as

inferiorly and leftward, and a terminal negativity, as left atrial depolarization forms the last part of the P wave and is directed posteriorly and to the left (Surawicz & Knilans, 2001). Placement of V_1 and V_2 electrodes too high on the chest is a common cause for the P wave in V_2 to be biphasic or negative (see Figure 1; García-Niebla, 2009). Recently, while reviewing ECGs taken at my institution in order to select tracings suitable for training our cardiology fellows, I encountered more tracings having purely inverted P waves in V_2 than seemed reasonable. This prompted the following investigation which was an attempt to shed further light on this phenomenon.

The author takes full responsibility for all aspects of the reliability and freedom from bias for the data presented and their discussed interpretation.

FIGURE 1 Leads V_1 and V_2 from an ECG study in which tracings were recorded in the 2nd through the 5th left and right parasternal intercostal spaces (ICS) in an attempt to duplicate an initial ECG done in the emergency room on a 65-year-old man complaining of atypical chest pain. A diagnosis of septal infarction of uncertain age was made initially based on an ECG in which it appears that V_1 and V_2 had been taken with those leads in the 3rd ICS. Note the disappearance of the initial r wave in V_2 as the leads were moved above the 4th ICS, and development of a negative P in V_2 when leads were placed in the 2nd ICS. His ECG was basically normal when leads were correctly placed. For similar symptoms, he had recently performed an exercise stress test which was negative for symptoms or signs of myocardial ischemia. An echocardiogram was also normal. ICS = intercostal space

2 | METHODS

2.1 | Selection of ECGs

Of the roughly 5,000 clinical 12-lead ECGs processed through the UCLA ECG laboratory in 1 month in 2015, 1,435 tracings were randomly selected for evaluation of the gender-related incidence of P-wave morphology in V_2 . The following characteristics caused exclusion of tracings from analysis: ECGs from patients under 18 years of age; those not showing sinus rhythm; dextrocardia; tracings having baseline artifact precluding clear evaluation of P morphology in V_2 ; patient duplication. The resulting 1,435 ECGs were initially divided into three groups: those with purely upright P in V_2 (PPV₂), those with biphasic P in V_2 (BPV₂), and those with purely negative P in V_2 (NPV₂). Eighty-four additional cases with NPV₂ were subsequently culled from a prior ECG archive in order to increase the number of such cases for study. Electronic medical records from selected cases in the group with a NPV₂ were reviewed with special attention to the presence of contemporary medical history and physical exam,

blood studies that might shed light on acute myocardial damage or heart failure, chest x-ray, cardiac imaging such as echocardiography, and additional 12-lead ECGs done either before or after the sentinel study.

Absence of septal Q waves was defined as the absence of a Q deflection in all of leads I, V_5 , and V_6 , as advocated by Burch (1956).

2.2 | ECG machines used

Electrocardiograms had been recorded with multichannel machines which routinely collect simultaneous 12-lead information (G.E. Marquette Model MAC 1500; G.E. Marquette Electronics, Milwaukee, WI, USA). Tracings were printed out at 25 mm/s paper speed and voltage calibrated at 1 mv = 1 cm.

2.3 | Statistical methods

Incidences amenable to expression in 2 by 2 tables were compared with a chi-square test or with a two-tailed Fisher's exact test when numbers were small. Group mean values are expressed $\pm$ the standard deviation, and differences between means studied by ANOVA. Significant difference was set at $p < .05$.

2.4 | Institutional review

This study protocol was approved by the appropriate institutional review board, which waived the requirement for obtaining informed consent from study subjects. This protocol conforms to the ethical guidelines of the 1975 Declaration of Helsinki.

3 | RESULTS

3.1 | Relation of gender

Of the initial 1,435 ECGs that met criteria for analysis of P wave polarity in lead V_2 , 1,216 (84.7%) had PPV₂, 150 (10.5%) had BPV₂, and 69 (4.8%) had NPV₂. Of the 1,216 with PPV₂, 716 (59.9%) were male and 500 (41.1%) were female. Of the 69 with NPV₂, 23 (33.3%) were male and 46 (66.7%) were female. Thus, patients with a NPV₂ were significantly more likely to be female than were those with a PPV₂ ($p < .001$). The 150 subjects with BPV₂ had an intermediate gender split (79% or 52.7% male and 71% or 47.3% female). This was not significantly different from those with PPV₂ ($p > .5$), but did differ significantly from those with NPV₂ ($p < .01$).

3.2 | Associated findings in lead V_1

In 94 out of 100 tracings with a NPV₂, an entirely negative P wave was present in lead V_1 . Of the six cases with a biphasic P in V_1 , one had RS and T progression in right precordial leads indicating reversal of V_1 and V_2 electrodes. In all cases with a NPV₂, the degree of P wave negativity in V_1 was greater than or less commonly equal to that of the P wave in V_2 . An electrocardiographic diagnosis of left

atrial enlargement by the criterion of Morris et al. (1964), which uses the magnitude of negative P terminal forces in V_1 , was very common in cases with a NPV_2 , as exemplified in Figure 2. As this criterion has been shown not to be specific for left atrial enlargement, but can be caused by other left atrial abnormality (LAA) or interatrial conduction defect, the term "LAA" will be used (Josephson, Kastor, & Morganroth, 1977). Analyzed in detail were 25 cases picked especially for the absence of any ECG abnormality other than an inverted T wave in V_2 accompanying the negative P wave in that lead. The presence or absence of an accompanying electrocardiographic LAA was not used as a selection criterion. This group of 25 included 23 women and two men. Only five were under 40 years of age, 18 had no clinical evidence of heart disease, five had mild hypertension, one had an asymptomatic pericardial cyst, and only one had known ischemic heart disease. In nine, cardiac imaging by echocardiogram or nuclear MUGA blood pool scan confirmed the clinical impression of the absence of heart disease. An ECG diagnosis of LAA was made in 19 of these 25 cases on the basis of the prominent negative P terminal forces in V_1 . Eight of these 19 cases had echocardiograms but only one of these showed evidence of left atrial enlargement. In 17 of these 19 cases, at least one additional ECG was available for review, and in 14 of these, a change from a negative to a biphasic or positive P in V_2 abolished the criterion for LAA in lead V_1 ; in the remaining three cases, there was NPV_2 in all available ECGs, and the criterion for LAA in V_1 remained present.

3.3 | QRS changes in V_2

Of the total 153 cases available for analysis with a NPV_2 , 32 cases (20.9%) also had a QS or Qr complex in that lead, usually leading to an electrocardiographic diagnosis of septal myocardial infarction. This group was made up of 19 women and 13 men. Nineteen of these 32 (59.4%) also had an inverted T wave in V_2 . This was similar to the frequency of that finding in the cases with a NPV_2 but with an rS or rSr' in that lead (69 of 121 cases (57.0%; $p > .5$). Only eight of the 32 had a clinical diagnosis of ischemic heart disease. Twenty-one had cardiac imaging with echocardiography or nuclear myocardial perfusion scan, but only three of these showed evidence of ventricular wall motion abnormality or scar.

Twenty-one of these 32 cases with QS or Qr in V_2 had multiple additional ECGs archived, and in 14 of these cases, at least one 12-lead tracing was present showing a PPV_2 and an rS complex in that lead in the absence of any clinical event intervening between that date and that of the sentinel tracing (see Figure 3 for an example). An additional four cases showed at least one ECC with a BPV_2 associated with an rS complex in that lead.

3.4 | Incidence of absent septal q waves

An unexpected finding was that in the above 32 cases with a QS or Qr complex accompanying an inverted P in V_2 , septal q waves were absent in 19 cases (59.4%). This was a much higher incidence than that

FIGURE 2 Right precordial leads from routine ECGs taken as part of routine annual physical exams on a healthy young woman, starting at age 27 years. The sentinel tracing shows ECG criteria for left atrial enlargement in V_1 , a completely negative P wave and T wave inversion in V_2 . The latter would usually be considered an abnormality. Sequential ECGs over the years showed biphasic P in V_1 , but P terminal negativity did not again meet criteria for left atrial abnormality, and P in V_2 was subsequently positive or biphasic with upright T wave, except in the last tracing where prominent P terminal negativity in V_2 was again associated with T inversion

FIGURE 3 Right precordial leads from ECGs on a 44-year-old woman, having a preoperative evaluation for reconstructive surgery on her right breast following recovery from mastectomy for breast cancer. She had a history of mild hypertension, but no evidence of cardiac disease. The sentinel tracing meets criterion for left atrial abnormality because of the magnitude of negative P terminal force in V_1 , and in V_2 it shows a Qr complex and negative T wave. The possibility of septal infarction was raised by these findings, which prompted performance of an echocardiogram, which was entirely normal. Repeat ECG 5 days later had similar findings, but a tracing 4 months later, in the absence of any intervening clinical event, showed an upright P wave in V_1 and V_2 as well as an rS complex and upright T in V_2 . Except for low QRS voltage (also present on prior ECGs), this ECG was normal

present in the remaining 121 cases with an initial r wave in V_2 (21 of the 121% or 17.4%: $p < .001$). No case with absent septal q waves met criteria for incomplete left bundle branch block. QRS duration was slightly but not quite significantly greater in these cases than in those with septal q waves (95.3 ± 11.7 ms vs. 87.2 ± 4.2 ms, $0.10 > p > .05$).

3.5 | Changes in the T wave in V_2

In 100 ECGs selected from this population because of a clearly PPV_2 , only three cases (3%) had a negative T wave in V_2 , and in each of these, negative T waves extended into lead V_3 , or even out to V_6 , and a clear clinical explanation was present for these abnormal T waves. In 148 cases with clearly NPV_2 , 86 cases (58.1%) had negative T waves in V_2 , and in the two of these in which T-wave inversion extended out to V_3 or beyond, an acute or recent myocardial infarction explained that. Thus, T-wave inversion in lead V_2 was much more common in tracings with a NPV_2 than in those with a PPV_2 : 86 out of 148 versus three out of 100 ECGs; $p < .001$. In 100 cases with BPV_2 , 16 (16%) had an inverted T in that lead, but in none of these did T-wave inversion extend into V_3 . These cases with BPV_2 thus had a significantly higher incidence of an associated T-wave inversion in that lead than was found in cases with PPV_2 : 16 out of 100 cases versus three out of 100 cases, $p < .01$. However, this was a significantly lower incidence of T inversion in V_2 than was present in cases with NPV_2 : 16 out of 100 cases versus 86 out of 148 cases, $p < .001$.

Of the 25 cases of NPV_2 described in a previous section having no ECG abnormality other than an inverted T wave in V_2 with or without a LAA, 23 had at least one other ECG for comparison. In 15 of the latter, a PPV_2 was associated with an upright T; in three cases, a BPV_2 was

associated with an upright T wave; in two cases, the P in V_2 became biphasic or upright but the T wave remained inverted; and in three cases, P and T waves both remained negative in V_2 . Figure 2 shows examples of change in T polarity in V_2 associated with changes in P polarity in that lead.

As mentioned above, in the few cases, where T-wave inversion was also present in precordial leads to the left of V_2 , there was usually ECG or clinical evidence of heart disease that would explain that T abnormality.

3.6 | Frequent change in P wave polarity from one ECG to another

From the group of sentinel tracings with a NPV_2 , 30 cases were selected on the basis of the presence of one or more additional archived ECGs from different dates either before or after the sentinel ECG. Of these 30 cases, 19 showed at least one other tracing with a BPV_2 , and there were 18 cases having a PPV_2 in other tracings. There were 13 cases showing BPV_2 in some ECGs, and PPV_2 in others.

Somewhat similar findings were noted in 30 cases selected because of a BPV_2 , and the presence of additional archived ECGs. A PPV_2 was found in other tracings in 18 cases, and a NPV_2 was found in 12 cases. There were five cases having PPV_2 in some ECGs and NPV_2 in others.

4 | DISCUSSION

4.1 | Limitations of the study

The findings in this study are limited by its retrospective nature and inability to reexamine the subject patients with exploring precordial

electrodes to see if anomalies thought to be due to errors in electrode placement could actually be reproduced by such a maneuver. Resources available and approved study protocol did not permit such luxury. Thus, it was not possible to test directly a major assumption, that in the absence of intervening clinical events, morphologic changes from ECG to ECG over time were most likely due to varying precordial lead placement. Unblinded review of the tracings and available clinical data by the author allowed possible bias to be present in interpretation of results.

4.2 | Significance of findings in this study

That a NPV₂ was found significantly more commonly in women than in men is consistent with the presence of female breast soft tissue making it more difficult to identify correctly parasternal intercostal spaces.

4.3 | Abnormalities that may be caused by high V₂ placement

Other than a negative P wave in V₂, a biphasic P in V₂ may result from high lead placement (García-Niebla, 2009). The latter study found no cases of NPV₂ and only two cases of BPV₂ in 100 adult subjects when leads V₁ and V₂ were correctly placed in the 4th parasternal intercostal spaces. Also an increase in magnitude of terminal P negativity in lead V₁ sufficient to prompt a false diagnosis of LAA can be caused by high V₁ and V₂ placement. Loss of initial r in V₂ can also result in a QS or Qr in that lead, leading to an incorrect diagnosis of septal myocardial infarction (Ilg & Lehmann, 2012; MacAlpin, 2004).

The significance of a higher than expected incidence of absent septal q waves in cases with a QS or Qr in V₂ is not clear. Although none of these cases met criteria for incomplete left bundle block, some variant of left septal fascicular block could be responsible, as that may cause loss of septal q waves and initial R waves in V₂ (MacAlpin, 2003). It may be a normal variant in up to about 15% of adult ECGs without any other abnormality (MacAlpin, 2001). Uhley (2001) has pointed out that infarction strictly limited to the interventricular septum may present with the loss of septal q waves as the only finding, but that does not seem to be the cause here.

And finally, T-wave inversion in V₂ in adults is not usually a normal finding, except in uncommon cases of persistent juvenile pattern of precordial T waves (Massie & Walsh, 1960). So it may suggest the possibility of septal ischemia, right ventricular strain, or other ventricular repolarization abnormality.

High placement of V₂ implies that V₃ will also be slightly misplaced, as it supposedly lies half way on a straight line between V₂ and V₄ (Kligfield et al., 2007). But the small changes in the resulting V₃ recorded usually do not produce an abnormality in that lead (e.g., see Figures 2 and 3) (Kania et al., 2014).

These false diagnoses due to improper electrode placement can expose the patient to additional, unnecessary cardiac testing.

Repeating the ECG with special attention to right precordial lead placement should most easily solve the dilemma.

4.4 | Difficulties in proper placement of lead V₂

As noted before, when right precordial electrodes are correctly placed, an entirely negative P wave of sino-atrial origin in lead V₂ is extremely rare (García-Niebla, 2009; Surawicz & Knilans, 2001), and should raise the possibility of abnormally high placement of that electrode on the chest. A BPV₂ may also be a clue to high lead placement (García-Niebla, 2009; Ilg & Lehmann, 2012), and the findings of this study are consistent with these suggestions. The correct placement of that electrode in the 4th intercostal space at the left sternal edge requires the ability to count intercostal spaces on the anterior chest, which may not be easy in patients who are obese, in women with prominent breasts, and in cases of severe malformations of the thoracic cage (Kligfield et al., 2007; Wenger & Kligfield, 1996). Cardiac electrical potentials recorded from lead V₂ are more subject to significant change from small changes in electrode position than are those of other standard precordial leads (Kania et al., 2014). In the case of the sinus P wave, this may be due to the closeness together of isopotential lines in the region of V₂ during P wave inscription (Mirvis, 1980).

My personal observations of the performance of clinical ECGs over the last 55 years suggests that they are less likely to be done by well-trained ECG technicians than in the past, and that medical personnel doing them now are therefore less likely to take the trouble actually to count anterior intercostal spaces, as this requires a very "hands-on" action. This impression is shared by other electrocardiographers (Kligfield et al., 2007). A frequent result of this is placement of V₂ (and V₁) one or two interspaces above the correct position (Wenger & Kligfield, 1996). While in many cases, this does not cause a normal ECG to turn into an abnormal one, the results of this study are consistent with the hypothesis that high placement of V₂ can cause falsely abnormal ECGs to be produced that mimic significant cardiac abnormalities, which can result in labeling of a patient with an incorrect diagnosis of heart disease and exposure to unnecessary additional tests and expense. It can also result in important cardiac diagnoses being missed (Bond et al., 2012).

4.5 | Prevention of lead placement error

One of the easily detected signs suggesting high placement of V₂ is a NPV₂ when sinus rhythm is present. A BPV₂ should also suggest that possibility. These findings are usually not noted by either current computerized analyses of the 12-lead ECG, or the cardiologist over-reader. The best solution to this problem is its prevention. As ECG readers are rarely present when the ECG is actually recorded, prevention requires that personnel doing them need to be trained to recognize by easily visualized ECG findings the possibility of lead misplacement before the patient is disconnected from the electrodes. This would allow correction of any lead placement error before the tracing is sent for interpretation, which is usually long after the patient has gone home. It should be simple to modify

computer-generated ECG interpretation software to include recognition of these features as a clue to high placement of V_1 and V_2 . In addition to a NPV_2 and BPV_2 , other signs in that that lead that are suggestive of its high placement are QS or Qr in the absence of other ECG abnormalities (MacAlpin, 2004), and an inverted T wave with no ST-T abnormalities in other leads. When an ECG reader recognizes one or more of these abnormalities in V_2 , mention of the possibility of lead placement error should be part of the formal interpretation, with a recommendation for repeat ECG with special attention to placement of right precordial electrodes. I have seen multiple examples where this simple strategy prevented incorrect diagnosis of heart disease and obviated the need for further, more expensive cardiac workup.

4.6 | Other possible significance of negative P in V_2

In a few cases, a negative sinus P wave in V_2 may not be due to high lead placement. In some patients, the electrical heart position may be low relative to its usual relation to the chest wall landmarks. Deformities of the chest wall could cause this. The finding by Kaykha et al. (2010) that the depth of P wave inversion in V_1 and V_2 was a significant predictor of cardiovascular death needs to be confirmed.

5 | CONCLUSIONS

A NPV_2 in lead V_2 is supposed to be rare when leads are placed correctly (García-Niebla, 2009; Surawicz & Knilans, 2001), but it seems to occur more frequently at the author's institution than in past years. The findings of this retrospective study and review of the literature on the matter are consistent with the hypothesis that a negative or even a biphasic P wave in that lead is often due to high placement of V_2 , which can also cause artifactual QRS and T abnormalities. The presence of these P morphologies should alert those taking ECGs and ECG readers to the probability of such a lead placement error.

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CONFLICT OF INTEREST

None.

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