Electrocardiographic T- and U-Wave Discordance

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Background: Abundant information has been reported regarding the U wave, which almost entirely has been focused on U waves in isolation. There has been little investigation of discordant T and U waves.

Methods: Of 18,750 consecutively recorded electrocardiograms, 143 patients were categorized resulting in three groups. Group A: 53 patients with negative T waves and positive U waves (Type I Discordance); Group B: 26 patients with positive T waves and negative U waves (Type II Discordance); and Group C: 63 patients with negative T and negative U waves. Each patient's chart was reviewed for relevant clinical, laboratory, and medical history.

Results: Coronary disease was slightly more common in Group A (64%) than in Group B (46%) ($P = 0.174$; ns). Coronary disease in Group C was extremely common (88%; $P < 0.001$). Hypertension in the two discordant groups was similar: Group A (60%) versus Group B (58%) ($P = \text{ns}$), Group C was significantly higher (88%) ($P < 0.001$). Left ventricular hypertrophy was 49% in Group A and 58% in Group B ($P = \text{ns}$), but Group C was significantly higher at 70% ($P = 0.038$).

Conclusions: This appears to be the first investigation of the associations of discordant T and U waves. We found that the significance of any U wave is not independent of their respective T wave. In addition, we propose that the U wave not be analyzed in isolation, but rather with respect to its T wave.

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The significance of the electrocardiographic U wave remains to be fully elucidated. The U wave, first mentioned by Einthoven in 1906¹ is normal, usually inconspicuous and can be recognized in up to 70% of healthy adults.² The U wave generally has the same polarity as the T wave and is usually most prominent in precordial leads V_2 - V_3 . On an average, normal U-wave amplitude is 10% of its T-wave's amplitude,³ and tends to be inversely related to heart rate; at rates exceeding 90-100 beats per minute normal U waves are usually indistinct,^{4,5} whereas bradycardia, hypokalemia, advanced age, and medications such as Class Ia antiarrhythmic agents and amiodarone increase U-wave amplitude.⁶

POSITIVE U-WAVES

Positive U waves can have a favorable prognostic significance. In a cohort of 1013 men, those

with detectable positive U waves had a decreased incidence of myocardial infarction over a 10-year period compared to a matched group without evident U waves.⁷ Although a positive U wave of normal amplitude may thus be beneficial, a negative U wave seldom occurs in the absence of heart disease.⁸

NEGATIVE U WAVES

Negative U waves occur in ~1% of hospitalized patients,⁹ most commonly in association with systemic hypertension, aortic or mitral regurgitation, and ischemic heart disease.¹⁰ Negative U waves also portended a higher incidence of heart failure post myocardial infarction; the sensitivity of the negative U wave to predict a global ejection fraction $< 45\%$ was 91.6% with a specificity of 82%.¹¹⁻¹³ Yet, in hypertensive patients there was no relationship between U wave inversion and left ventricular hypertrophy (LVH).¹⁴

CHANGES IN U-WAVE POLARITY

Changes in U-wave polarity have prognostic implications. U-wave inversion has been identified several hours prior to other electrocardiogram (ECG) changes in acute myocardial infarction.^{15,16} Exercise induced U-wave inversion is highly predictive of significant coronary artery disease; negative U waves in the precordial leads during exercise had a higher specificity (88% vs 70%) and positive predictive value (77% vs 61%) for ischemia than ST depression.^{17,18}

POLAR T-U RELATIONSHIPS

Normally, T- and U-wave polarities are concordant. In aVR for example, a negative U wave with a negative T wave is expected and unremarkable. Yet, although the U wave has been extensively studied, there has been little attention to the behavior of the U wave in regard to its T wave, i.e., T-U polar relationships. U waves, particularly negative U waves, have been studied widely in isolation irrespective of the polarity of the preceding T wave. We considered T-wave polarity by investigating polar T-U discordance compared with T-U concordance.

METHODS

Standard 12-lead ECGs showing discordance and negative T- and U-wave concordance were segregated from 18,570 consecutive ECGs. Discordance is defined as T-wave polarity clearly opposite to U-wave polarity in one or more leads (V_1 is omitted, given the intersubject variability of its T-wave). U-wave inversion was considered present when there was a discrete negative deflection (>0.5 mv) from the TP baseline in leads in which the T and U waves would normally be positive.¹⁹ Positive U waves were defined as an upright U waves >0.5 mm following a T wave. The possibility of terminal T-wave inversion was excluded by determining QT interval in other leads where U-wave inversion was not present.¹¹

All medical records were reviewed for patient age, sex, medications, and any significant medical or surgical history. Specific attention was given to documented history of systemic hypertension, coronary artery disease (confirmed by cardiac catheterization, clinical myocardial infarction, or autopsy findings of coronary atherosclerosis), LVH (confirmed by echocardiogram), valvular heart dis-

ease (confirmed by echocardiogram and catheterization), and clinical heart failure. Patients were excluded if significant electrolyte abnormalities existed, uncontrolled hypertension,²⁰ atrial fibrillation, or heart rate >100 bpm.⁴ Finally, a positive or negative U wave is exceedingly difficult to differentiate in atrial fibrillation or flutter, which distort the baseline and were therefore excluded.

In addition, ECGs were segregated according to T- and U-polarity. Each ECG with discordant U waves was analyzed for rate, rhythm, QRS axis, diagnostic Q waves, ST, and T-wave abnormalities, and conduction disturbances. Group A ($n = 53$) consisted of ECGs with negative T waves and positive U waves (Type I Discordance) (Fig. 1). Group B ($n = 26$) had positive T waves and negative U waves (Type II Discordance) (Fig. 2). Group C ($n = 64$) had negative T waves and negative U waves (Negative concordance) (Fig. 3).

STATISTICAL ANALYSIS

Statistical analysis was performed with SYSTATTM 6.0. The chi-square test by Fisher's direct method was used for comparison of categorical data. Differences were considered statistically significant at $P < 0.05$.

RESULTS

Table 1 compares Group A and Group B; Table 2 compares combined T- and U-wave discordance (Groups A + B) with concordance (Group C). Seventy-nine of the 18,750 ECGs showed T-U-wave discordance (Groups A + B prevalence = 0.4%). The first 64 ECGs with negative concordance were drawn from the same population (Group C prevalence $\sim 1\%$). Mean age of patients in Groups A, B, and C was 71, 74, and 71 years of age, respectively. Groups A and B had a female to male ratio of 1.4:1. Group C had a 1.1:1 ratio. Age and sex among the three groups revealed no statistically significant differences. Noncardiac comorbidity was analyzed; the two most prominent coexisting diseases were diabetes mellitus and COPD. Twenty-nine percent of the patients had COPD with no statistically significant difference among the three groups ($P = 0.821$; ns). Twenty-eight percent of the patients had some form of diabetes mellitus ($P = ns$). The highest number of patients with diabetes was in Group C: 34% ($P = ns$).

Figure 1. Representative electrocardiogram of Type I Discordance—Group A (negative T and positive U) in leads V₃–V₆.

There was a high overall prevalence of cardiovascular disease (Table 1). Coronary artery disease was slightly more common in Group A (64%) compared to Group B (46%); however, this was not statisti-

cally significant ($P = 0.174$). Coronary artery disease in Group C was extremely common 88%. Hypertension in the two discordant groups was similar: 60% in Group A versus 58% in Group B. Group

Figure 2. Representative electrocardiogram of Type II Discordance—Group B (positive T and negative U) in leads V₄–V₆.

Figure 3. Representative electrocardiogram of concordant—Group C (negative T and negative U) in leads I, aVL, V₂–V₆.

C was again higher with 88% of the patients with clinically evident hypertension ($P < 0.001$). Congestive heart failure tended to be more common in Group C at 44% ($P = 0.098$; ns), whereas Group A had a prevalence of 30% and Group B 31% ($P = 0.958$). Echocardiographic LVH was also very common: 49% in Group A versus 58% in Group B ($P = 0.47$; ns), but Group C (70%) had significantly more LVH ($P = 0.038$). Similar results were found among the three groups for A-V blocks and valve disor-

ders. A-V blocks were similar in Groups A and B (22% vs 15% prevalence, respectively; $P = \text{ns}$). Group C had a nonsignificant higher incidence of A-V block (30%). Valve diseases were prevalent in 4% of the total patients with nonsignificant differences among the three groups.

No statistical significant difference was found between Groups A and B with regards to all the variables in Table 1. However, the combination of the discordant T-U Groups (A + B) compared to the negatively concordant T-U. Group C achieved

Table 1. Discordant Groups A and B

Study Group	NegT/PosU Group A	PosT/NegU Group B	P Value
Number	53	26	
Age	71	74	ns
Percent male	42%	42%	ns
LVH ^a	26 (49%)	15 (58%)	ns
Conduction disturbances	12 (22%)	4 (15%)	ns
Hypertension	32 (60%)	15 (58%)	ns
Coronary artery disease	34 (64%)	12 (46%)	ns
Congestive heart failure	16 (30%)	8 (31%)	ns
Valvular disease	10 (19%)	6 (24%)	ns
Atrial fibrillation	9 (17%)	3 (12%)	ns
COPD	14 (26%)	9 (35%)	ns
Diabetes mellitus	15 (28%)	4 (15%)	ns

^aPatients with an echocardiogram.

Table 2. Discordant Groups (A + B) Compared with Concordant Group C

Study Group	Group A + B	Group C	P Value
Number	79	64	
Percent male	42%	52%	ns
LVH ^a	41 (52%)	30 (70%)	0.038
Conduction disturbances	16 (20%)	19 (30%)	ns
Hypertension	47 (60%)	56 (88%)	<0.001
Coronary artery disease	46 (58%)	56 (88%)	<0.001
Congestive heart failure	24 (30%)	28 (44%)	ns
Valvular disease	16 (20%)	19 (30%)	ns
Atrial fibrillation	12 (15%)	19 (30%)	ns
COPD	25 (32%)	17 (27%)	ns
Diabetes mellitus	19 (24%)	22 (34%)	ns

^aPatients with an echocardiogram.

Table 3. Negative T Groups versus Positive T

Study Group	(NegT/PosU) (NegT/NegU) Group A + C	(PosT/NegU) Group B	P Value
Number	117	26	
Age	72	74	ns
LVH ^a	56 (48%)	15 (58%)	ns
Hypertension	88 (75%)	15 (58%)	ns, P = 0.16
Coronary artery disease	89 (76%)	12 (46%)	P = 0.002
Congestive heart failure	44 (38%)	8 (31%)	ns

^aPatients with an echocardiogram.

statistical significance when comparing hypertension ($P < 0.001$), LVH ($P = 0.038$), and coronary artery disease ($P < 0.001$) each more prevalent with negative T-U concordance (Table 2).

DISCUSSION

To date, little is known specifically about the T- and U-wave discordance. The negative U wave has been studied extensively and is now well known to be associated with increasing age, heart disease, and hypertension.^{12,14,21,22} For example, a negative U wave by resting ECG has previously shown 89% specificity for CAD.²³ The negative U wave has been in addition studied in "dynamic" conditions: exercise testing, PTCA, myocardial infarction, and during angina.^{24,25} Positive U waves, for example, are associated with a decreased risk of future cardiac disease.⁵ Although all of these studies showed that a negative U wave was highly correlated with disease, none analyzed the U wave in association with T-wave polarity.

In addition, we analyzed the two types of T-U-wave discordances (Types I and II) with respect to the significantly correlated variables: CAD, hypertension, LVH, and CHF. The two discordant groups were similar without any statistically significant differences in relation to cardiovascular disorders or major medical comorbidities. As expected, from the literature, our concordant Group C (negative T and negative U waves) showed a high prevalence of cardiovascular disease. The summary of the two discordant groups (Table 2) highlights the significant differences between the two combined discordant groups versus the concordant group, especially, with regard to the major diagnoses: hypertension, coronary artery disease, and LVH.

Given the significant cardiac disease noted in Group A (negative T and positive U) it is evident

that in this relationship, at least, a positive U wave can be associated with significant cardiac disease which is contrary to investigations of positive U waves in isolation. In addition, given the significantly reduced hypertension, coronary artery disease, and LVH in Group B (positive T and negative U) compared to the concordant group it is clear that a negative U-wave in the presence of a positive T wave reveals unexpected results. Thus, the significance of any U waves was not independent of that of their T waves.

To assess the significance of a negative T wave within these three groups, we combined Groups A and C, and compared the data to Group B (positive T and negative U) (Table 3). Only one variable, coronary artery disease, demonstrated statistically significant differences 76% versus 46% ($P = 0.002$). The lack of differences between these two groups may well have to do with the small sample size of Group B.

This investigation demonstrated that the two groups with discordant T and U waves are statistically comparable in regard to the variables in Table 1. Moreover, a negative U wave following a positive T wave or a positive U wave following a negative T wave is significantly less associated with certain cardiac diseases than are concordantly negative T and U waves. Thus, the significance of U waves is not independent of their T waves. We propose that (1) the U wave should not be analyzed in isolation, but should be examined in conjunction with the T wave and (2) our clinical results have not explained U-wave discordance; discordant U waves should be investigated electrophysiologically.

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