SPECIAL REPORTS

The Year of 2006 in Electrocardiology

Shlomo Stern, M.D.

From The Hebrew University of Jerusalem, Jerusalem, Israel

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Highlighting the important contributions to the science of electrocardiology published in peer-reviewed Journals during the year 2005¹ prompted the observation that ECG is "still the cardiologist's best friend."² In this article, I have tried to test whether this last year's phrase did not melt with last year's snow. By reading the following, our readers will be able to judge.

THE P WAVE

A detailed analysis of the P-wave morphology in focal atrial tachycardia was done by Kistler et al.,³ who classified them as positive, negative, isoelectric, or biphasic. The authors prospectively evaluated 30 new consecutive patients with focal atrial tachycardia. Their P-wave algorithm correctly identified the site of tachycardia origin in 93%. Lead V₁ was the most useful in identifying the likely anatomic site of the origin of the focal atrial tachycardia.

THE QRS COMPLEX

The prognostic power of computer-measured QRS duration was evaluated by Desai et al.⁴ in a general medical population. The QRS duration score was shown to be a strong independent predictor of cardiovascular mortality: for every 10-ms increase in QRS duration, there was an 18% increase in cardiovascular risk. The results were similar in patients with an abnormal ECG, with BBB and with paced rhythms. Similar conclusions were reached

by Bauer et al.⁵ in post-MI patients in whom a prolonged QRS duration (≥ 120 ms) showed the highest association with total and late mortality, but not with sudden death and serious arrhythmic events.

Fragmented QRS (fQRS) was defined as the presence of an additional R wave, notching in the S wave, or >1 R' in two contiguous leads.⁶ Patients with typical BBB or incomplete right BBB were excluded by study design. This study confirmed by using myocardial perfusion imaging that the presence of fQRS on standard 12-lead ECG was more accurate than identification of Q waves, as a valuable sign for prior MI and scar.

In the HERO-2 trial,⁷ Wong et al. studied the influence of different BBB types on prognosis. Right BBB accompanying anterior MI at presentation and newly developed right or left BBB early after fibrinolytic therapy were found to be independent predictors of high 30-day mortality. The authors suggested that these ECG features should be considered in risk stratification to identify high-risk patients. In the same trial⁸ on multivariable analyses, an increasing QRS duration by 20-ms increments was associated with increasing 30-day mortality in both right BBB groups; patients with QRS duration ≥ 160 ms had a higher 30-day mortality than those with QRS duration <160 ms. Also, this trial showed that initial Q waves accompanying ST elevation worsened 30-day mortality.⁹

Late potentials were detected in 62% of postventriculotomy patients with congenital heart disease by Perloff et al.,¹⁰ who stressed the increased risk for monomorphic VT in these patients.

Address for reprints: Shlomo Stern, M.D., 1 Shmuel Hanagid Street, Medical Building, Jerusalem 94592, Israel. Fax: 972-2-625-8862; E-mail: sh_stern@netvision.net.il

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THE QT INTERVAL

In the Rotterdam study, a "dose-response effect" was seen by Straus et al.¹¹ between QTc duration and the risk of SCD in the age group 55–68 years and those >68 years. An abnormal QTc prolongation, >450 ms for men and >470 ms for women, was an independent risk factor for SCD. Two-thirds of cases with SCD were shown to have an abnormally prolonged QTc interval. Hiromoto et al.¹² demonstrated that various indices of beat-to-beat QT interval variability that reflected the infarction site in frequency domain correlated with LV function, but the indices of the RR intervals in frequency domain did not correlate with LV function. This phenomenon may be a result of autonomic imbalance toward sympathetic over activity or vagal withdrawal.

An effect on the QT interval was among the ECG parameters in humans relevant to a decreased arrhythmic risk. Tuna and other broiled or baked fish consumption was associated with lower heart rate, slower atrioventricular conduction, and a substantially lower likelihood of a prolonged QT.¹³

THE T WAVE

T-wave morphology analysis by Linna et al.¹⁴ demonstrated that KCNH2 K897T polymorphism was associated with the total cosine R-to-T (TCRT), which reflects the wave from direction between depolarization and repolarization. Subjects with a less common genotype, KT or TT, have smaller TCRT, which reflects dyssynchrony between depolarization and repolarization and may increase their vulnerability to arrhythmic events.

Neurogenic T wave appearance preceded the clinical acute stroke picture in a patient described by Lindberg and Jauch.¹⁵ ECG revealed deep, symmetric T-wave inversions, consistent with neurogenic T waves; the patient developed only 50 minutes after this initial ECG, left-sided hemiplegia, facial droop, eye deviation, and hemineglect.

THE LONG QT SYNDROME

In LQTS patients, there is a considerable variability in QTc measures in serial follow-up ECGs and the maximum QTc interval provides incremental prognostic information beyond the baseline measurement. Goldenberg et al.¹⁶ suggested

that risk stratification in LQTS patients should include follow-up ECG data of both symptomatic and asymptomatic patients. The detection of QTc of >500 ms at any time during follow-up identified patients at high risk for arrhythmic events. The authors stressed the importance of the maximum QTc interval recorded before the age of 10.

The ECG patterns of the arrhythmia onset and symptom triggers in congenital LQT syndrome were studied by Tan et al.¹⁷ Pause dependence was predominant in LQT2 but was rare or absent in LQT1; in the latter torsades de pointes started without significant changes in the duration of the preceding RR intervals. The different arrhythmia mechanisms may explain why pause-preventing pacemakers may be required in LQT2, while β -adrenergic blockers as single treatment are effective in LQT1.

Vitasalo et al.¹⁸ proved with the use of 24-hour ECG recordings that in patients with LQT1 β -blockers at heart rates of >85 bpm shortened both the diurnal maximal T-wave peak to T-wave end interval and the maximal ratio between late and early T-wave peak amplitude, which are ECG counterparts of transmural dispersion of repolarization and early afterdepolarizations, respectively. These observations are in concert with the clinical experience of using β -blocking medication for the reduction of cardiac events in LQT1 patients.

The predictive power of the QTc interval in all ECG leads was studied by Moenning et al.¹⁹ in 200 consecutive genotyped LQTS family members with the purpose of using receiver operating curve analysis for identifying mutation carriers and high-risk LQTS patients. Additionally, the risk for events (syncope and sudden cardiac arrest) was calculated for QTc decile in all individuals. The predictive power was highest in lead II and lead V₅ for identifying carriers in LQTS families and were optimal for risk stratification.

LQTS contributes to sudden infant death syndrome. Quaglini et al.²⁰ analyzed the cost-effectiveness of a nationwide program of neonatal ECG screening and demonstrated that the program was cost-effective and allowed the early identification of still asymptomatic infants with LQTS.

In children with LQTS an ambulatory 12-lead system demonstrated macroscopic T-wave alternans, intermittent extreme QT prolongation, and T-wave notchings and in those suspected for tachyarrhythmia, several SVTs and VTs.²¹

SHORT QT SYNDROME

Giusetto et al.²² reinforced the concept that SCD is the most relevant clinical manifestation of short QT syndrome and that these events may occur in infants and other children. Since ICD implantation during childhood remains a technical challenge in a very young short QT syndrome patient with a high-risk profile, oral quinidine may represent a bridge to ICD implant later in life.

T-WAVE ALTERNANS

An upsurge in TWA was demonstrated by Shusterman et al.²³ preceding VT. TWA increased by 10% 30 minutes before and by 25% 10 minutes before the VT started and was not attributable to an increase in heart rate. The specificity of the upsurge in TWA before VT was, however, not proved in this article.

In a relatively low-risk post-MI population with preserved ejection fraction a positive microvolt TWA test was the most significant predictor on multivariate analysis for SCD or life-threatening arrhythmic event and had the highest sensitivity and negative predictive value for these events.²⁴ According to the authors, microvolt TWA can be used for risk stratification in this low-risk population. In the study of Kaufman et al.²⁵ in patients with left ventricular dysfunction even an "indeterminate" microvolt TWA when due to ectopy, unsustained microvolt TWA, or low exercise heart rate, had similar to a positive test prognostic significance for death or sustained ventricular arrhythmia. Similarly, in patients with ischemic cardiomyopathy, a positive or indeterminate microvolt TWA test was an independent predictor of arrhythmic and all-cause mortality with a modest predictive value, as shown by Chow et al.²⁶

ISCHEMIA/INFARCTION DIAGNOSIS

The precise ECG diagnosis of acute MI was the subject of several recent investigations. In a multicenter study, the prevalence of failure to identify high-risk ECG findings (significant ST-segment depressions, ST-segment elevations, or T-wave inversions) in emergency departments was studied by Masoudi et al.²⁷ In patients with confirmed acute MI on presentation, the failure rate was 12%. Rates of missed ECG findings by hospitals ranged from 5.6% to 15.1%. Missed high-risk findings were less common among patients with ST segment eleva-

tion than for those with T-wave inversion. The in-hospital mortality of the patients with missed high-risk ECG findings was 7.9% compared with 4.9% among those without missed findings.

In ST-elevation acute MI patients in the MONAMI study,²⁸ continuous ST-monitoring was initiated in the pre-hospital phase and continued during and 90 minutes following PCI. Patient classification based on the ST monitoring result was useful for risk stratification at time of PCI into groups with low, intermediate, and high risk profile. Westerhout et al.²⁹ demonstrated that the degree of ST-segment depression on 12-lead baseline ECG was the highest contributor to the prediction of 30-day and 1-year mortality and 30-day death/MI in a contemporary sample of 7800 non-ST-elevation ACS patients, beyond troponin T, creatinine clearance, N-terminal pro-brain natriuretic peptide, heart rate, and age.

The concordance between the location of an acute myocardial infarction by the ECG patterns and by cardiac MR showed that abnormally increased R waves, the Q-wave equivalent, in leads V₁ and V₂ indicate a lateral-wall MI and that abnormal Q waves in leads aVL and I without a Q wave in lead V₆ indicate a mid-anterior MI.³⁰ Accordingly, the terms "posterior" and "high lateral" MI are incorrect when applied to these patterns and it is suggested that these should be changed to lateral-wall and "mid-anterior wall" MI, respectively.

In patients with inferior ST-elevation MI V4R yielded information, which led to an enhanced use of fibrinolytic therapy, as shown by Harju et al.³¹

Unipolar intracoronary ECG recording from the angioplasty catheter guidewire has been shown by Balian et al.³² to be more sensitive and reliable to detect myocardial injury than standard ECG. By obtaining tracings before and after PCI, the authors determined the degree of ST-segment elevation or depression compared with the baseline intracoronary ST-segment. Patients who had a significant ST-segment shift of ≥ 1 mm were more likely to have myonecrosis, as measured either by troponin or CK-MB and had a trend toward a greater number of hard clinical events. Of five patients who suffered a fatal or nonfatal MI, four had an ST-segment shift of ≥ 1 mm.

In a case control study with a first ST-elevation MI, in VF survivors cumulative ST-segment elevation was shown to be significantly greater preceding the VF than in controls, whereas infarct size was similar in the two groups, according to an analysis

by Dekker et al. of 330 primary VF survivors and of 372 controls.³³

ARRHYTHMIA DETECTION

New information derived by Rosman et al.³⁴ analyzing patients with ICDs showed that a VPB initiated the VT in 58 episodes (92%), 1 episode was initiated by a supraventricular tachycardia, and 4 episodes had sudden onset.

The prematurity ratio was significantly higher in patients with ischemic cardiomyopathy as compared to patients with nonischemic cardiomyopathy. This may represent different mechanisms of VT initiation in patients with ischemic versus nonischemic heart disease.

In apparently healthy persons without history or clinical manifestations of heart disease, 2-minute ECG demonstrated VPBs in 6.2% in over 15,000 examinees in a study by Massing et al.³⁵ After a follow-up of >10 years, the mortality was >3 times greater for those with VPBs compared with those without VPBs. Similar results were reported by Sajadieh et al.,³⁶ who found that single VPBs on a standard ECG were significant predictors of frequent VPBs and an independent predictor of all-course mortality and acute MI. Thus, VPBs even in apparently healthy individuals warrant awareness and meticulous risk assessment.

THE BRUGADA SYNDROME

In the Brugada syndrome type 1, i.e., the "coved-type" ST-segment is mandatory for the diagnosis. In 43 consecutive patients of Brugada syndrome, Weltman et al.³⁷ found in only one patient a consistent type 1 ECG, whereas in about half of them it appeared and disappeared transiently during the follow-up, and in the others was only inducible by drugs. Thus, a patient's risk for future events may be underestimated if it is based only on an initial nondiagnostic ECG, and repetitive ECG recordings therefore seem to be mandatory. Daily fluctuations in the magnitude of the right precordial ST-segment elevations and the appearance of late potentials might possess predictive power for future events.³⁸

Unmasking the Brugada type 1 ECG phenotype as a result of amiodarone therapy was reported by Paul et al.³⁹ in a patient with atrial fibrillation and poorly controlled ventricular rate. An intravenous amiodarone infusion was commenced that not only

restored sinus rhythm within 12 hours, but also, unmasked the classic features of type 1 Brugada syndrome. Discontinuation led to a resolution of the ECG changes.

EXERCISE ECG

For years, most experts have advocated that upsloping ST-segment depression during exercise testing does not indicate ischemia. Recently,⁴⁰ retrospective analysis of 621 exercise tests on patients, who have had nuclear scintigraphy and coronary angiograms within a 3-month period, showed that 20% of patients with this configuration had a large area of reversible ischemia on the gated SPECT acquisition and 28% had triple-vessel disease on coronary angiography. Consequently, when upsloping ST changes were considered abnormal, the sensitivity of the exercise EKG increased to 82% when compared to the gated SPECT imaging and to 77% when using the angiogram as the gold standard, while the specificity remained about the same.

Kligfield and Lauer⁴¹ in a recent report stressed that beyond recognizing "simple" ST depression, the measuring of heart rate adjustment of the ST depression, QRS duration and amplitude, QT- and T wave changes, ST recovery loops and hysteresis, improve the diagnostic capability of exercise testing. High frequency components of the QRS complex that are not usually represented in the routine ECG tracing, between 150 and 250 Hz, have been shown by Abboud and Zlochiver⁴² to decrease in the presence of acute ischemia.

HYPERTENSION

In hypertensive patients, a strain pattern, defined as a down-sloping convex ST segment with inverted asymmetrical T-wave opposite the QRS axis in lead V₅ or V₆, was shown by Okin et al.⁴³ to represent an increased risk of developing heart failure and of dying as a result of heart failure. This was found also even in the setting of aggressive blood pressure lowering, suggesting that more aggressive therapy may be warranted in hypertensive patients with a strain pattern.

PROGNOSTIC VALUE OF ECG

The prognostic information from the 12-lead ECG in noncardiac surgery candidates with coronary artery disease was studied by Jeger et al.⁴⁴ ST depression and faster RR intervals remained

independent predictors of all-cause mortality after adjustment for clinical baseline findings. Faster heart rate was also an independent predictor of major adverse cardiac events at 2 years.

The importance of a prehospital 12-lead ECG was demonstrated by showing that it reduces the median time to fibrinolytic therapy in the hospital by 32 to 62 min.⁴⁵

GENDER DIFFERENCES

In contrast to the widespread conception that the ECG is of limited utility in women, Okin et al.⁴⁶ stressed recently that in female patients the value of the ECG for risk stratification was similar to that in males. Rautaharaju et al.⁴⁷ studied five ECG variables in men and women and found them to be equally significant mortality predictors in both genders. The same group of investigators described the repolarization abnormalities in postmenopausal women, which predict coronary events and death.⁴⁸

In women ≥ 90 years young, presenting for any reason, a normal ECG tracing was found more frequently than in men in the similar age group (6% vs 2%).⁴⁹

ECG IN CARDIOMYOPATHY

In restrictive cardiomyopathy due to amyloidosis a striking ECG evolution was shown by Leeson et al.⁵⁰: ST-segment change, reduced QRS amplitude, increased P wave width and amplitude, and progressive increase in PR interval. P-wave morphology demonstrated additional significant atrial involvement. Restrictive cardiomyopathy leads to bi-atrial enlargement and increased P wave amplitude and width. Furthermore, atrial amyloid deposition delays atrial conduction and thereby increases the PR interval and broadens the P wave. The bi-atrial pathologies were clearly demonstrated in this patient by cardiovascular magnetic resonance imaging.

The ECG findings in 102 hypertrophic cardiomyopathy patients were compared with the results of cardiac magnetic resonance by Dumont et al.⁵¹ Abnormal Q waves were associated with greater upper anterior septal thickness and increased ratios of upper anterior septum to mean inferolateral, anterolateral, apical, and right ventricular wall thickness. Wider Q waves, conduction disturbances, and absent septal Q waves were associated with late-

enhancement. The depth of negative T waves was related to craniocaudal asymmetry and apical late-enhancement.

ECG IN MYOCARDITIS

In parvovirus B19 myocarditis patients frequently present predominantly with severe chest pain of acute onset in a manner similar to that of myocardial infarction; most had typical subepicardial late gadolinium enhancement in the lateral wall. This combination of ischemia and inflammation explains, according to Mahrholdt et al.,⁵² the infarct-like ECG and elevated troponin level.

CONCLUSIONS

Even without reporting here on dramatic advances during 2006 in electrocardiology, in view of the uninterrupted flow of hundreds of new, original, and inventive articles, I am confident to say that ECG is today the most widely used important method in cardiology. The reviewed 50 outstanding innovative articles prove the relevance of ECG not only for diagnosis, but also for decision making regarding the therapies available today and for identifying the individual at high risk for cardiac events and for sudden cardiac deaths.

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