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QT Dispersion in Unipolar Precordial Leads

Paul Kligfield, Ken W. Lee, and Peter M. Okin

Division of Cardiology, Weill Medical College of Cornell University,
and the New York-Cornell Center of New York- Presbyterian Hospital

Correspondence: Paul Kligfield, Cornell Medical Center, 525 East 68th Street, New York, New York 10021 USA.
E-mail: *pkligfi@mail.med.cornell.edu*, phone +212 746 4686, fax +212 746 8561

Abstract. Increased QT dispersion has clinically important predictive value for arrhythmic substrate and adverse prognosis in patients with ischemic heart disease. However, the mechanism responsible for variability of QT intervals on the surface ECG is unclear. Although QT dispersion on the standard ECG is commonly related to heterogeneity of repolarization in underlying ventricular myocardium, recent studies indicate that QT dispersion might more simply be explained by abnormalities of the T wave loop that result in isoelectric projection in one or more of the precordial leads. These findings suggest that alternative descriptive measures of morphology of the ST segment and T wave might become useful markers of risk in this important patient population.

Keywords: *QT Interval; Repolarization; T Wave, Coronary Artery Disease; Predictive Value*

1. Introduction

Clinical interest in QT dispersion on the surface ECG is rooted in electrophysiologic observations that regional heterogeneity of action potentials in adjacent cardiac muscle tissue can initiate and propagate sustained arrhythmias [Han and Moe, 1964; Kuo et al., 1983; Antzelevitch et al., 1991]. In the intact heart, these arrhythmias can lead to hemodynamically unstable ventricular tachycardia or ventricular fibrillation, each of which can cause sudden death. Because sudden death is a major catastrophic complication of many common cardiac disorders, including ischemic heart disease, considerable recent attention has been focused on diagnostic methods for the identification of patients who are at increased risk. Regional heterogeneity of repolarization can be detected by comparison of intramyocardial electrograms and from electrical signals recorded directly from the surface of the heart. Extrapolation of these findings from regional action potentials and from epicardial electrograms to the QT intervals of the routine ECG leads generates the working hypothesis that QT dispersion might be an important predictor of cardiac arrhythmias and mortality [Day et al., 1990; Pye et al., 1994].

2. Clinical Observations of QT dispersion

Recent clinical studies have demonstrated that dispersion of measured QT intervals from individual leads of the surface ECG increases with disease and has important predictive value for inducible ventricular arrhythmia, sudden death, and other cardiac events in a wide range of cardiovascular diseases. In chronic ischemic heart disease, prolonged QT dispersion measured from the standard ECG has been associated with acute ischemia [Sporton et al., 1997] and its prognostic value has been demonstrated in patients with chronic coronary artery disease [Zareba et al., 1994; Trusz-Gluza et al., 1996]. In patients after myocardial infarction, prolonged QT dispersion has been associated with the extent of myocardial viability and with vulnerability to ventricular tachycardia and ventricular fibrillation [van de Loo et al., 1994; Perkiömäki et al., 1995; Glancy et al., 1996a; Perkiömäki et al., 1997; Gabrielli et al., 1997; Oikarinen et al., 1998].

Prolonged QT dispersion also has been found to have predictive value in other forms of heart disease. As summarized in a recent report, these include chronic heart failure, hypertrophic cardiomyopathy, mitral valve prolapse, aortic stenosis, and hypertension [Lee et al., 1998]. The link between prolonged QT dispersion and arrhythmogenesis is highlighted by pharmacologic studies in patients with the long QT syndrome and with torsades de pointes [Hii et al., 1992; Priori et al., 1994]. Predictive value of prolonged QT dispersion for inducible ventricular arrhythmias in patients with a variety of diagnoses has been shown to persist after adjustment for standard risk factors, including the presence of late potentials on the signal-averaged ECG and subnormal ejection fraction [Lee et al., 1997].

3. Mechanisms of QT Dispersion

Despite the evident clinical usefulness, the mechanism underlying the predictive value of observed QT dispersion remains uncertain. QT dispersion in patients with ischemic heart disease is commonly attributed to heterogeneity of ventricular repolarization detected in underlying myocardium by individual unipolar precordial leads. Because the standard central terminal has relatively constant potential, the unipolar precordial leads might record unique voltage changes under individual electrodes even on the body surface. This can be defined as "local effect". Since regional contribution to unipolar lead voltage varies exponentially with distance, and the heart is not situated in the center of the thorax, it is possible that the precordial leads preferentially record local rather than remote potential variations. If this occurs, a plausible explanation for the useful predictive value of measured QT dispersion is that it reflects the heterogeneity of repolarization within adjacent regions of myocardium that is known to be arrhythmogenic.

However, QT dispersion might also be explained simply by interlead variation in projection of the T wave vector onto the different precordial leads. This can be defined as a "projection phenomenon". Once an exploring electrode is removed from direct contact with the heart to the surface of the body, its ability to record unique information from subjacent tissue is limited. A unipolar electrode on the body torso must record the underlying potential differences from both local and remote myocardium, as represented by the instantaneous heart vector. Low amplitude T waves and T wave loops that are round in the horizontal plane can produce isoelectric components of repolarization that would result in apparent dispersion of QT measurements in the unipolar precordial leads. It has long been recognized that abnormal T wave loops are a feature of important coronary artery disease [Hoffman et al., 1966], and since abnormal repolarization is also associated with adverse prognosis in heart disease, this could provide an alternative reason for the observed useful predictive value of QT dispersion.

Vector projection and regional variation are not mutually exclusive principles, and each might affect the surface ECG in different ways. The distinction between these processes is schematically illustrated in Fig. 1.

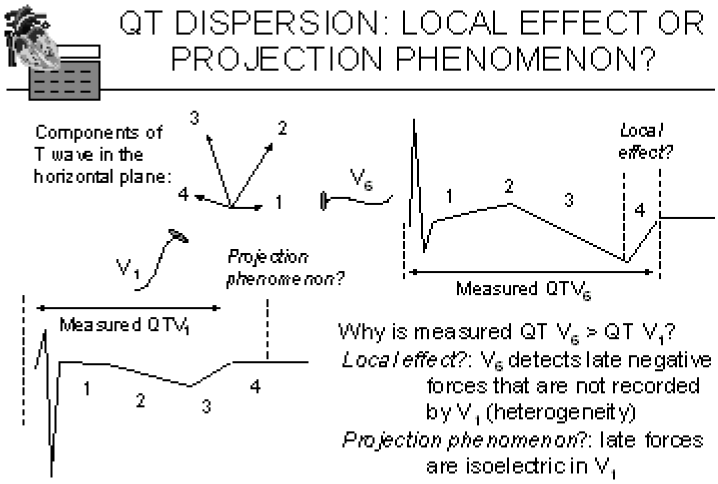

Figure 1. In this schematic illustration, the terminal negative component that lengthens the QT in V6 is isoelectrically projected onto V1. Is the QT dispersion that results a "local effect" or a "projection phenomenon"?

In this context, QT dispersion measured from routine ECGs might result as much or more from isoelectric projection of the T wave as from underlying heterogeneity of repolarization. This would not detract from the established prognostic value of increased QT dispersion in patients with various forms of heart disease, but it would modify our appreciation of the mechanism of this relationship. Accordingly, we evaluated the potential contribution of the projection phenomenon to the measurement of QT dispersion in normal subjects and in patients with coronary artery disease.

4. QT Dispersion and the Projection Phenomenon

Interlead variation of ECG measurements during depolarization and repolarization depend on the relative placement of electrodes on the body, the distance of exploring unipolar electrodes from the heart, and the magnitude and orientation of the underlying electrical forces. The effect of vector projection on interlead differences of ECG measurements can be separated from local effects of regional heterogeneity. With respect to QT dispersion, measurement of interlead differences of QT interval can be made under conditions in which interlead dispersion of repolarization is not possible. Regional heterogeneity of QT intervals is eliminated when analysis is limited to the bipolar and unipolar limb leads that are mathematically derived from two bipolar frontal plane electrode pairs during simultaneous lead acquisition of computerized ECGs [Kors et al., 1999]. QT dispersion due to heterogeneity of repolarization should also be greater in standard ECGs than in tracings that are synthesized directly from three orthogonal leads [Macfarlane et al., 1998].

To further examine the potential magnitude of apparent QT dispersion that can be attributed to the projection phenomenon, we eliminated local heterogeneity effects by transformation of 12 lead ECGs into derived ECGs based on the heart vector [Lee et al., 1998]. The analog device used to produce the derived ECGs was developed by Dr. Gordon Dower. It first generates an orthogonal representation of the heart vector by transformation of the standard 12 lead ECG and then synthesizes the derived 12 lead tracing by means of a separate algorithm. Because the derived ECG is synthesized only from the heart vector data, it is not merely a mathematical recreation or restoration of the original tracing, and it contains no information that is unique in the derived "unipolar, precordial" leads.

We examined paired standard ECGs and derived ECGs in 129 men and women (mean age 50 years) with normal resting ECGs that were taken prior to elective surgical procedures [Lee et al., 1998]. We also examined paired standard and derived ECGs in 78 hospitalized patients (mean age 67 years) with established coronary artery disease [Kligfield et al., 1998], most of whom had abnormal repolarization on the standard ECG. The QT interval in each precordial lead was measured from the first deflection of the QRS complex to the end of the T wave, and dispersion was calculated as the difference between maximum and minimum precordial values. When low amplitudes of the T wave made measurement points uncertain, individual leads were excluded from calculation to avoid differences based on obvious measurement error.

In these studies, mean precordial QT dispersion from the standard ECGs of patients with ischemic heart disease (51 ms) was greater than the mean QT dispersion measured from the standard ECGs of the normal subjects (41 ms). In each population, the average magnitudes of QT dispersion that were measured from the derived ECGs were similar to those measured from the standard 12 lead ECGs. Since the derived ECGs by definition contain no heterogeneity of repolarization duration in the precordial leads, it is evident that the projection phenomenon can create apparent QT dispersion in normal subjects and in patients with coronary disease that is similar in magnitude to that measured from standard ECGs.

5. Discussion

These findings do not exclude heterogeneity of repolarization as a factor in the QT dispersion measured from the standard ECG of some patients. Recognition of the projection phenomenon in no way reduces the importance of variability of action potential duration in arrhythmogenesis. However, these findings do suggest that precordial QT dispersion found on the standard ECG is not equivalent to regional heterogeneity of repolarization in normal subjects and in some patients with coronary artery disease.

The magnitude of QT dispersion measured in the standard precordial leads of these patients is similar to the dispersion that can be explained by variable precordial projection of the T wave loop. These observations, taken together with those of others [Macfarlane et al., 1998; Kors et al., 1999], suggest that apparent QT dispersion may be more a measure of T loop shape than a measure of regional heterogeneity of repolarization. Indeed, rounding of the T wave loop in patients with coronary artery disease and with other forms of heart disease is evident in the vectorcardiographic work of Hoffman et al. [1966], among others. In these studies, a ratio of the long axis and its perpendicular transverse dimension was used to quantify the shape of the T wave loop, and this ratio was shown to differ in normal subjects and in patients with ischemic disease. Abnormality of repolarization on the ECG alone and on the vectorcardiogram is an important sign of coronary disease and a predictor of coronary events. The recent observation that T wave loop morphology can be a marker for cardiac events in the elderly [Kors et al., 1998] is consistent with these principles and observations.

It is therefore possible that the prognostic value of QT dispersion on the surface ECG is more closely related to its novel description of abnormal repolarization than to its representation of local heterogeneity of action potentials. If so, it also is possible that other quantitative approaches to classification of ECG repolarization might provide additional insight into the natural history of ischemic disease. Alternative, and possibly complementary, descriptors are particularly desirable in view of the methodologic difficulties inherent in accurate measurement of QT intervals. Recognized problems include accurate determination of the end of the T wave in the presence of low amplitude T waves and precision and reproducibility of the measurement [Kautzner et al., 1994; Murray et al., 1994, Glancy et al., 1996b]. In this context, principle component analysis of the T wave appears to be a promising mathematical improvement of the early quantitative vectorcardiographic approach noted above that is adaptable to standard computerized electrocardiography [Xue and Reddy, 1997; Priori et al., 1997; Okin et al., 2000].

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