QT Dispersion and T-Loop Morphology in Late Pregnancy and After Delivery

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Summary
The aim of the study was to detect changes of both the QT dispersion and T-loop morphology resulting from the changed spatial position of the heart during pregnancy. Electrocardiographic and vectorcardiographic recordings were obtained from 37 healthy women 19-36 years old in the 36th to 40th week of physiological pregnancy and 2 to 6 days after delivery. The same recordings were obtained from 18 healthy women of the same age. The average QT dispersion (±S.D.) in normal subjects was significantly lower (34±12 ms) than in those in late pregnancy (73±18 ms) (P<0.001). The average amplitude of T-loop (Ta) in women in late pregnancy was significantly (P<0.001) smaller (532±98 µV) and the width of T-loop (Tw) was wider (21.24±11.48 deg) than in the control group (793±114 µV and 7.17±3.02 deg, respectively). The partial post-partum restoration of all parameters was not significant. In all groups, the QT dispersion was significantly correlated with Tw but not with Ta. According to these results we can conclude that the QT dispersion is an indirect reflection of the complete process of ventricular repolarization, reflected in the morphology of the T-loop.

Key words
QT dispersion • Electrocardiography • Vectorcardiography • T-loop morphology • Pregnancy

Introduction
According to experimentally obtained data (Han et al. 1964, Merx et al. 1992), increased temporal dispersion of refractoriness has been suggested to be very closely related to the increased vulnerability of the ventricular myocardium to serious tachyarrhythmias. The duration of the myocardial refractoriness (the time between depolarization of cells by an activating wavefront and repolarization) is thought to be represented by the interval between the onset of the Q wave and the end of the T wave on the ECG curve. Delayed cardiac electrical recovery (repolarization) could therefore be detectable by the prolongation of the QT interval. Each of the ECG leads is aimed to derive information from a different aspect of the ventricular myocardium. Therefore, each ECG lead represents another region of the heart muscle mass. As the myocardium is generally an inhomogeneous tissue there are regional differences in action potential duration. Therefore, one lead can represent the area of earliest repolarization by the shortest QT interval whilst another one indicates the area of the
heart which is last to be depolarised by the longest QT interval (Fig. 1). The difference between them is known as QT dispersion which is thought to be representative of the overall variability in the timing of repolarization (Day et al. 1992).

However, another concept of QT dispersion origin has been discussed recently, suggesting that rather than regional heterogeneity of myocardial repolarization, different projections of the 3-dimensional T-wave loop into individual ECG leads accounts for the possible differences in QT interval duration (Kors et al. 1999, Batchvarov and Malik 2000). According to this concept, there is only one end of repolarization, which is the final common termination for all leads together, when the electric field dissolves and all potential differences vanish. If the electrical potential recorded on any ECG lead equals zero this means that there is no difference between two electrodes composing the lead (including precordial leads), because the central terminal by no means constitutes a zero potential (Burger 1955). In other words, the projection of the instantaneous heart dipole is perpendicular to the given lead. Consequently, the shortest QT duration can be expected to occur in the lead where the terminal part of the T loop is perpendicular to the lead axis (Fig. 2). According to Kors et al. (1999) several factors come into play to explain the relation between QTd and T loop morphology. Especially two parameters of the T loop could be crucial: 1) spatial T loop amplitude (Ta) and 2) T loop width (Tw).

**Fig. 1.** Standard interpretation of QT dispersion: Each lead represents another area of myocardium. If there is a difference in two areas as far as the duration of the action potential is concerned, there will also be a different QT interval duration on the recording leads.

**Fig. 2.** Different amplitudes registered on a lead due to different direction of instantaneous vector.
Nevertheless, many studies have demonstrated a direct relation between increased QT dispersion and different cardiovascular pathologies. Mirvis (1985), using body surface mapping, detected increased QT dispersion in patients after acute myocardial infarction, and his finding was repeatedly confirmed (Cowan et al. 1988, van de Loo et al. 1994). Later, increased QT dispersion was found in arrhythmia patients with long QT intervals (Day et al. 1990, Linker et al. 1992, Priori et al. 1994), in patients with drug-induced torsades de pointes tachycardias (Hii et al. 1992, Hohnloser et al. 1993) and also in patients with lethal arrhythmias (Somberg et al. 1985, Barr et al. 1994). Sporton et al. demonstrated in 1997 that an acute increase in QT dispersion can be caused by induced myocardial ischaemia.

Although it seems safe to conclude on the basis of these studies that QT dispersion is of major importance in detecting repolarization abnormalities, yet its mechanism is still not clear. While QT dispersion could result from underlying heterogeneity of ventricular repolarization (i.e. as a direct measure of the recovery time dispersion), it also could result from a variable projection of single three-dimensional vector dynamics onto different ECG leads (i.e. as an indirect measure of general repolarization abnormalities).

In order to contribute to solve this question, we have used late pregnancy as a model of the physiologically changed spatial arrangement of thoracic organs accompanied by deviated morphology of the T-loop. Thus, this model has enabled us to study the relation between QT dispersion and spatial aspects of the T-loop.

Patients and Methods

Patients

Electrocardiographic recordings were obtained from 37 healthy non-obese women aged between 19-36 years with physiological pregnancy in the 36th to 40th week and in the 2nd to 6th day after spontaneous physiological delivery. The same recordings were obtained from the control group containing 18 volunteers, healthy non-pregnant, non-obese women aged between 20-36 years.

A healthy person was defined for the purposes of this project according to the following criteria: negative cardiological family and personal history, normal arterial blood pressure, normal glycemia, normal cholesterolemia, normal ECG, non-smoker, normal body weight, negative neurological and endocrinological personal history, no cardiological medication.

Measurements

The examination was carried out under standard conditions by only one examiner in order to assure full compatibility and reproducibility of the obtained results in all the examined groups. Data acquisition was performed in the morning and the examined women were allowed to relax for a few minutes before the recordings. While examined they were asked to remain still and to avoid any movement.

Electrocardiographic and vectorcardiographic recordings were obtained simultaneously using the Cardiac 112.2 device (Kittnar et al. 1993). The QT interval was measured from 80 unipolar chest leads used for body surface potential mapping. It was measured from the start of the Q wave to the end of the T wave, each QT interval was corrected for the patient’s heart rate (QTc) using Bazett’s formula (van de Loo et al. 1994). QT dispersion was then defined as the difference between the maximal and minimal QT interval in any of the leads measured. Accordingly, QTc dispersion was defined as the difference between maximal and minimal heart rate-corrected QT interval QTc. Vectorcardiographic recordings were obtained from Frank’s orthogonal leads, angles and amplitudes of the T-loop were measured at 3 time instants (1/4, 1/2 and 3/4 of the whole T-loop duration) in all three perpendicular planes (frontal, transversal, and left sagittal). From the measured data the spatial T-loop amplitude (Ta) and T-loop width (Tw) were then calculated. Tw was defined as the space angle between T vectors at the 1/4 and 3/4 instants of the T-loop (Fig. 3).

Data analysis

The computer program of the Cardiac 112.2 device was used for the processing of the electrocardio-
graphic and vectorcardiographic data. This program determines the common wave onsets, offsets and amplitudes for all 95 leads in one representative beat. The set of all leads comprised: 12 standard ECG leads, 3 orthogonal Frank’s vectorcardiographic leads and 80 regularly placed unipolar body surface leads (Kittnar and Štoviček 1993).

The QT intervals were measured manually by a single observer from curves on the device screen. The cursor indicated the start of the Q wave and the end of the T wave. The curves were displayed on the screen at a speed corresponding to a paper shift of 50 mm/s and a gain of 1mV/cm. To check the reproducibility of the measurement we assessed both intraobserver and interobserver variability. For determining the intraobserver variability, all ECG tracings were evaluated by the same investigator on two different occasions. To assess the interobserver variation, all ECG tracings were analyzed by a second independent investigator who was ignorant of the results obtained by the other. T-loop parameters were also measured manually from curves on the device screen. The cursor was used to indicate the three crucial instants of the T-loop (1/4, 1/2 and 3/4 of the T-loop duration), the amplitudes and angles were then automatically calculated by the computer program.

Statistical evaluation of the assessed data was performed using the ANOVA method for repeated measurements.

Table 1. Statistically significant differences in electrocardiographic and vectorcardiographic parameters, QT and QTc dispersion and T-loop parameters (p<0,05).

<table>
<thead>
<tr>
<th></th>
<th>Control group (n=18)</th>
<th>Late pregnancy (n=37)</th>
<th>After delivery (n=37)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate (l/min)</td>
<td>75.2 (11.5)</td>
<td>102.1 (18.2)</td>
<td>97.2 (16.3)</td>
</tr>
<tr>
<td>QT interval (ms)</td>
<td>365.2 (30.5)</td>
<td>323.7 (29.3)</td>
<td>334.3 (19.0)</td>
</tr>
<tr>
<td>QTc interval (ms)</td>
<td>405.3 (20.7)</td>
<td>442.3 (28.9)</td>
<td>418.5 (22.0)</td>
</tr>
<tr>
<td>QT dispersion (ms)</td>
<td>34 (12)</td>
<td>73 (18)</td>
<td>64 (20)</td>
</tr>
<tr>
<td>QTc dispersion (ms)</td>
<td>36 (13)</td>
<td>79 (21)</td>
<td>62 (23)</td>
</tr>
<tr>
<td>T wave, axis (deg)</td>
<td>27.6 (14.8)</td>
<td>18.8 (9.1)</td>
<td>16.0 (11.9)</td>
</tr>
<tr>
<td>QRS-T, space angle (deg)</td>
<td>25.6 (20.9)</td>
<td>37.8 (19.7)</td>
<td>45.3 (34.0)</td>
</tr>
<tr>
<td>Ta (µV)</td>
<td>792.9 (104.3)</td>
<td>532.1 (98.4)</td>
<td>561.8 (117.2)</td>
</tr>
<tr>
<td>Tw (deg)</td>
<td>7.17 (3.02)</td>
<td>21.24 (11.48)</td>
<td>14.05 (12.32)</td>
</tr>
</tbody>
</table>

Numbers are the mean values± S.D., f – frontal plane, other abbreviations see text.

Results

Reproducibility of the determination of QT dispersion was high in both intraobserver and interobserver comparisons. In absolute numbers, the difference between the first and second determination of QT dispersion in the same ECG tracing (intraobserver variability) ranged between 0 and 18 ms, with an average value of 8 (±3) ms. The values for interobserver variability varied between 0 and 21 ms, with a mean value of 9 (±5) ms.

The average QT dispersion (±S.D.) in the 18 normal subjects was significantly lower [34 (±12) ms] than in women in the late period of pregnancy [73 (±18) ms] (P<0.001). The results were very similar using rate corrected values with average QTc dispersion values of 36 (±13) ms for normal subjects and 79 (±21) ms for those in late pregnancy (P<0.001). In spite of the reduction of QTc interval after delivery, both QT and QTc dispersions were not significantly changed on the 2nd to 6th day after spontaneous physiological delivery and neither was there any significant change in the heart rate (Table 1).
Table 2. Parameters of the correlation between QTd and Tw

<table>
<thead>
<tr>
<th></th>
<th>Control group (n=18)</th>
<th>Late pregnancy (n=37)</th>
<th>After delivery (n=37)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient r</td>
<td>0.827</td>
<td>0.752</td>
<td>0.767</td>
</tr>
<tr>
<td>P</td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Regression equation</td>
<td>QTd = 18.0+2.2xTw</td>
<td>QTd = 60.7+0.6xTw</td>
<td>QTd = 51.6+0.8xTw</td>
</tr>
</tbody>
</table>

r - Pearson’s coefficient of correlation

![Fig. 4. QT dispersion (QTd) versus Tw plots in the control group and in the group of pregnant women both before and after delivery.](image1)

The average Ta in women in the late period of pregnancy was significantly (P<0.001) smaller [532 (±98) µV] and the Tw wider [21.24 (±11.48) deg] than in the control group [793 (±114) µV and 7.17 (±3.02) deg respectively]. The partial post-partum restorations of both parameters were not significant (Table 1, Fig. 5). In the control group, as well as in the group of pregnant women both before and after delivery, the QT dispersion was correlated well with Tw (Table 2, Fig. 4) but not significantly with Ta.

![Fig. 5. Changes of QT dispersion, QTc dispersion and Tw in late pregnancy and after delivery.](image2)

Discussion

The present study was aimed to determine the possible changes in QT and QTc dispersion in late pregnancy and after delivery from ECG curves using body surface potential mapping. The employment of a greater number of leads for determining QT dispersion appears to characterize the QT dispersion more accurately than assessment in only 12 or even 6 precordial leads. The use of a small number of leads was undoubtedly the
main cause of the repeatedly suggested poor reproducibility (Day et al. 1990, Kautzner et al. 1994). The enhanced accuracy for QT dispersion assessment from 12-lead ECG in comparison with only 6 precordial leads was also reported (van de Loo et al. 1994, Higham and Campbell 1994). Moreover, the reproducibility could be influenced by the scale of the ECG curve (paper speed and gain) and especially the lower time resolution (25 mm/s) was suggested to be an important reason for the poor reproducibility (Glancy et al. 1996). Both the intra- and interobserver variability of QT and QTc dispersion assessed in this study permits the use of this method to determine changes in QT dispersion as the detected changes lie well above the errors encountered in this study.

The present measurements indicate that the late pregnancy per se causes both a prolongation of QTc interval and an increase in the QT as well as QTc dispersion and that in spite of the reduced QTc interval both QT and QTc dispersion remain increased even after delivery (Table 1, Fig. 5). These findings are in close agreement with those of Mshui et al. (1999) in patients with simple obesity before and after diet therapy.

Our results suggest that it is necessary to re-evaluate the possible clinical importance of QT dispersion. While regional changes in action potential duration and conduction (increased electrical inhomogeneity of the myocardial tissue) can play an important part as QT dispersion determinants, other factors that could occur both in the heart itself and in the tissues lying between the ventricular myocardium and measuring electrodes on the body surface may well alter the QT dispersion. It must be emphasized that the surface electrocardiographic QT interval “reflects complex and interrelated aspects of cardiac electrophysiology, cardiac geometry, torso shape, tissue impedance, and biological signal processing” (Higham and Campbell 1994).

To study the possible physiological determinants of QT dispersion, we have evaluated electrocardiologic changes due to altered thoracic geometry. Changed spatial arrangement of abdominal organs during pregnancy results in increased pressure of the viscera on the diaphragm and thoracic organs. This is undoubtedly associated with the changed spatial position of the heart which is then accompanied by an “abnormal” pattern of the electrical heart field configuration, including the changed spatial relations between the heart and any ECG lead. Consequently, the morphology of vector-cardiographic loops must be changed as well. Change in the T wave axis in the frontal plane suggests a more horizontal position of the heart; this change, nevertheless, is not accompanied by a corresponding change in the QRS axis. This is apparently the cause of the increased QRS-T space angle in the frontal plane (Table 1). Our results suggest that it is necessary to re-evaluate the possible clinical importance of QT dispersion.

Nevertheless, in addition to the changed spatial arrangement of the chest organs two other factors could contribute to the electrocardiographic changes during pregnancy:

Changed electrical properties of the myocardium due to changed both sympathetic and hormonal modulation (epinephrine, progesteron) of the electrical heart activity. This can be to a certain extent in accordance with the hypothesis that increased QT dispersion is a marker of enhanced risk of arrhythmias as similar changes of neurohumoral cardiac modulation contribute very probably to such an increased risk and could also be involved in a delay of cardiac electrical recovery. This explanation appears to be in accord with our findings of changed electrical heart field in late pregnancy and after delivery (Lechmanová et al. 2001).

The changed impedance of tissues lying between the ventricular myocardium and measuring electrodes on the body surface is due to the gradual accumulation of sodium and total body water, most of which is extracellular during pregnancy. This explanation corresponds to our recent findings (Lechmanová et al. 2001) that most hemodynamic parameters changed in late pregnancy are completely restored in 4 days after delivery with only two exceptions: the heart rate and the thoracic fluid capacity. The persisting significant increase of thoracic fluid capacity can be caused by elevated blood flow in the thorax due to increased heart rate as well as by persistent increase in the total body fluid.

All electrocardiographic changes detected in late pregnancy are not partially restored until 4 days after delivery. This finding is in accordance with not fully restored body weight within 4 days after labor, probably due both to a persisting increase of total body fluid (increased thoracic fluid capacity) and to increased sympathetic activity. The latter could explain some changes of other variables, for instance increased heart rate.

As mentioned above, it has been hypothesized recently (Kors et al. 1999) that two parameters of the T-loop morphology (Ta and Tw) could affect QT dispersion.

Overall decreased spatial amplitude (Ta) of the T-loop will result in decreased amplitude of the T wave.
which could undoubtedly lead to increased QT dispersion because of the increased uncertainty in determining the end of low T waves (Kautzner et al. 1994, Murray et al. 1997). Although we have found increased QT dispersion corresponding to the decreased Td in late pregnancy, there was poor correlation between both parameters.

![Diagram of T-loop projection onto the lead axis and shortening of QT duration](image)

The wider the T-loop the higher the probability that the terminal T axis is perpendicular to the lead axis and consequently, the shorter the QT duration (Fig. 6). It may be questionable whether this fact alone could be sufficient to explain the difference in QT dispersion between pregnant women and the control group in our study. However, the lead axes of 80 precordial leads placed orderly on the whole torso surface are distributed in 80 different directions and they therefore receive different projections of the T-loop. The direction of the terminal T axis determines which lead will have the shortest duration and which will have the longest one. If the direction of the T-loop is changed without any change of its shape, the leads with the shortest and longest QT will change, but the difference between the longest and shortest QT (QT dispersion) will remain the same. However, if the width of the loop increases, the QT interval in corresponding leads will be shortened and the QT dispersion will be increased. This theoretical consideration is supported by the very good correlation between QT dispersion and Tw. Nevertheless, it would be erroneous to simply conclude that there is a causal relation between QT dispersion and Tw as both parameters represent an enormous simplification of the electrical heart field that is very complex and spreads towards the measuring electrodes through the inhomogeneous environment of the human thorax. In our opinion, both QT dispersion and T-loop morphology are able to reflect similar disorders of the repolarization pattern. In other words, we can conclude that the QT dispersion is an indirect reflection of the complete process of ventricular repolarization, reflected in the morphology of the T-loop. Moreover, the findings observed in our study suggest that the complexities of factors involved in the overall dispersion of repolarization needs to be explored systematically. The QT dispersion can reflect not only increased risk of serious tachyarrhythmias, especially due to myocardial ischaemia, but it was also proved in our study to be increased physiologically. Can such an increase be caused just by a changed spatial arrangement of the chest organs including the heart, or can it be due to changed patterns of neurohumoral cardiac modulation? This merits further investigation. However, we may conclude that the prolonged QT dispersion should be interpreted simply just as “an unspecific sign of changed course of repolarization”.

**Acknowledgements**

**Informed Consent**

The study was performed in compliance with Human Studies Guidelines of the First Faculty of Medicine, Charles University, Prague. The Ethical Committee of the Faculty of Medicine approved all procedures used in the study. The subjects were informed about all procedures and an informed consent was obtained from all subjects involved in the study after the nature of the administrations had been explained. A preliminary communication (Lechmanová et al. 2000) was presented at the Meeting of Czech and Slovak Physiological Societies, Hradec Králové, February 2-4, 2000. Supported by the Grant MSM 11110008.
References


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