Ilan Goldenberg, MD

Research Associate Professor:
Heart Research Follow-Up Program, University of Rochester Medical Center, Rochester NY.

Senior Cardiologist:
Sheba Medical Center, Tel Hashomer, Israel

DISCLOSURE INFORMATION
No relationships exist regarding this presentation
Presentation Title:

How to Measure QT
Abnormally long and short QT intervals are associated with increased risk for life-threatening ventricular arrhythmias and sudden cardiac death.

In recent years, various methods for QT interval measurement have been developed including:

- Individual-based corrections for repolarization duration
- Quantitative assessment of repolarization morphology
- Correction for repolarization dynamicity
- Analysis of repolarization variability
Purpose of Presentation

To describe clinically relevant methods for assessment of QT interval duration from a 12-lead ECG:

- Focus will be on simple methods that can be utilized in day to day practice for the diagnosis of long QT syndrome (LQTS) and other repolarization disorders
- Using visual and manual assessment
Methods of ECG Assessment

- **Manual ECG readings:**
  - Performed using visual determinations: “eyeball”/caliper techniques

- **Digitizing methods:**
  - Employ a digitizing pad, magnifying lamp, and pointing device to identify the beginning and end of the QT interval
  - Have an accuracy levels of 5 ms

- **On-screen computerized methods:**
  - Displays recorded ECGs on a computer screen
  - Provides high-quality ECG data
  - Recommended at core laboratories
Manual Assessment I

- The accuracy levels of manual determination with a caliper is 20 to 40 ms
- A standard 12-lead ECG tracing at 25 mm/s paper speed at 10 mm/mV amplitude is adequate
- The QT interval should be determined as a mean value derived from at least 3-5 cardiac cycles
- Measured from the beginning of the earliest onset of the QRS complex to the end of the T wave
The QT measurement should be made in leads II, and V5 or V6 with the longest value being used.

The main difficulty lies in identifying correctly the point where the descending limb of the T wave intersects the isoelectric line, particularly when there are T and U waves that are close together.

In general, biphasic T waves are frequently present in multiple leads, whereas discrete and separate low-amplitude U waves are best seen in the lateral precordial leads.

See next slide for examples of identifying T-wave end.
Identifying T-Wave End

A. The end of the T wave is identified when its descending limb returns to the TP baseline when it is not followed by a U wave.

B. The end of the T wave is identified when its descending limb returns to the TP baseline when it is distinct from the following U wave.

C. When T wave deflections of equal or near equal amplitude result in a biphasic T wave, the QT interval is measured to the time of final return to baseline.

D. If a second low-amplitude repolarization wave interrupts the terminal portion of the T wave, it is best to record both the QT interval (T wave offset measured as the nadir between the T and U wave) and the QTU interval (repolarization offset measured at the end of the second wave).
QRS Interval

• The QRS interval can be modified by several factors:
  - Bundle branch block,
  - Class 1C antiarrhythmic drugs
  - Preexcitation

• The QT interval in these cases may not be an accurate reflection of repolarization duration

• The measure of the JT, from the S wave offset to T wave end, may be used in these cases but normal standards for the JT interval are not well established
Adjustment for heart rate
Correlation formulae

- The time-duration intervals are influenced by heart rate (R-R cycle length), so heart rate correction is required in the analysis of repolarization duration.

- Various heart rate correction formulae have been developed in order to determine whether the QT interval is prolonged in comparison to its predicted value at a reference heart rate of 60 beats per minute (i.e. a RR interval of 1.0 second).

- These formulae have been derived mainly from resting ECGs and therefore require a stable sinus rhythm without sudden changes in the RR interval.
<table>
<thead>
<tr>
<th>Method</th>
<th>Formula</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exponential</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bazett</td>
<td>QTc = QT/RR$^{1/2}$</td>
<td>Widely used; may give erroneous results at both slow and fast heart rates.</td>
</tr>
<tr>
<td>Fridericia</td>
<td>QTc = QT/RR$^{1/3}$</td>
<td>Widely used; May give more consistent results at fast heart rates.</td>
</tr>
<tr>
<td>Linear</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Framingham</td>
<td>QTc = QT+0.154(1-RR)</td>
<td>May have more uniform rate correction over a wide range of heart rates.</td>
</tr>
<tr>
<td>Hodges</td>
<td>QTc = QT+1.75(HR-60)</td>
<td></td>
</tr>
<tr>
<td>Rautaharju</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Females and males &lt;15 and &gt;50 years</td>
<td>QTI = (QT[HR+100])/656</td>
<td>May have more uniform rate correction over a wide range of heart rates</td>
</tr>
<tr>
<td>Males 15-50 years</td>
<td>QTI= 100(QT)/([656/(1+0.01HR]) + 0.4age - 25)</td>
<td></td>
</tr>
<tr>
<td>Logarithmic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ashman</td>
<td>QT = K1 x log(10 x [RR + ])</td>
<td>At low heart rates, the values are too low.</td>
</tr>
<tr>
<td>Adult men:</td>
<td>K2= 0.07, and K1 = 0.380</td>
<td></td>
</tr>
<tr>
<td>Adult women</td>
<td>K2= 0.07, and K1 = 0.390</td>
<td></td>
</tr>
</tbody>
</table>
Correction Formulae: Summary of Data

- There is no general consensus on the best formula to be utilized in clinical practice

- In resting conditions, with heart rates in the 60 to 90 beats/min range, most formulae provide almost equivalent results for the diagnosis of QT prolongation

- The rate dependence of the QT interval is probably best described by an exponential relation. However, in the normal heart rate range, the QT-RR relation is approximately linear
Heart rate correction in patients with sinus arrhythmias
Assessment of repolarization dynamicity may be required in patients without a stable sinus rhythm:

- The QT interval adapts to heart rate changes with a delay known as QT hysteresis or QT lag.
- When the change in the heart rate persists for several minutes, the QT lag is visible on the trend of QT and RR intervals.
- The QT adapts more slowly to decelerations than to accelerations of the heart rate.
- The plot of QT versus RR intervals during dynamic adaptation of repolarization to heart rate changes forms a loop known as hysteresis.
- QT/RR hysteresis pattern is highly individual and therefore, methods which take into account individual profiles are required.
Assessment of repolarization dynamicity may be required in patients without a stable sinus rhythm:

- The QT interval adapts to heart rate changes with a delay known as QT hysteresis or QT lag.
- When the change in the heart rate persists for several minutes, the QT lag is visible on the trend of QT and RR intervals.
- The plot of QT versus RR intervals during dynamic adaptation of repolarization to heart rate changes forms a loop known as hysteresis.
- QT/RR hysteresis pattern is highly individual and therefore, methods which take into account individual profiles are required.
Normal values of the QT interval
Most reported criteria for normal and abnormal values for QTc are derived from Bazett's formula.

A study that was carried out at the Heart Research Follow-Up Program showed:

➢ Stable QTc for children, with no gender difference
➢ A significant difference between adult men and women in a healthy population

<table>
<thead>
<tr>
<th>Rating</th>
<th>1-15 years (msec)</th>
<th>Adult Male (msec)</th>
<th>Adult Female (msec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>&lt;440</td>
<td>&lt; 430</td>
<td>&lt; 450</td>
</tr>
<tr>
<td>Borderline</td>
<td>440-460</td>
<td>430-450</td>
<td>450-470</td>
</tr>
<tr>
<td>Prolonged</td>
<td>&gt;460</td>
<td>&gt; 450</td>
<td>&gt; 470</td>
</tr>
</tbody>
</table>
Simple graphical display of lower and upper limits of QT interval for different RR cycle lengths based on population studies.
Repolarization Morphology
Quantitative Assessment of Repolarization Morphology

- Quantitative repolarization assessment has recently become feasible for the following parameters:
  - Symmetry of the T wave
  - T wave area
  - The interval between the end of the S wave

- Requires computer software and electronically stored ECG data.
Visual Assessment of Repolarization Morphology in the Congenital Long QT Syndrome

- **LQT1:**
  - A single, smooth, broad-based T wave is common, as well as a late-onset normal-appearing T wave

- **LQT2:**
  - Bifid T waves are the hallmark ECG feature

- **LQT3:**
  - T-waves are typically late-onset, prominent, and usually peaked
T-wave Morphology in LQTS by Genotype

Other ECG Recording Techniques for QT Assessment
Holter monitoring is not well standardized to serve in the primary assessment for ventricular repolarization analysis.

- Holter may sometimes be employed for the detection of extreme QT interval events that occur infrequently during the day.

- QT intervals measured by Holter do not correspond quantitatively to those for standard ECGs, and therefore are not suitable for direct comparison.
Exercise Testing

- Can be used for evaluation of QT prolongation during exercise and recovery periods
- May be employed for the detection of extreme QT interval events that occur infrequently during the day
- Both intermittent 12-lead ECGs or continuous multichannel ECG recordings can be used
- The adaptation of QT interval duration to heart rate is not instantaneous, therefore, substantial errors may be introduced if nonstationary episodes are analyzed
Recent analysis from the International LQTS Registry demonstrates that there is individual subject variability in QTc duration on repeat ECGs during long-term follow-up.

Therefore several ECGs recorded over time should be more useful in identifying subjects with abnormally long or short QT intervals than simply one baseline ECG recording.

The maximum QTc on serial follow-up was shown to be the most powerful predictor of cardiac events in LQTS children.

Conclusions
Routine measurement of the QT interval requires the use of uniform criteria for the determination of:

- T wave offset (especially when there is partial superimposition of the T and U wave)
- Adjustment for heart rate
- T wave morphology.

Experience and training play an important role in the accurate measurement of the QTc interval.