MEASUREMENT

Errors in manual measurement of QT intervals

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Abstract

***Objective*—To quantify the errors associated with manual measurement of QT intervals and to determine the source of the errors.**

***Design*—A randomised study of QT measurement by four cardiologists of electrocardiograms plotted on paper in presentations with different noise levels, paper speeds, amplifier gains, and with and without a second QRST complex to indicate the RR interval.**

***Subjects*—Four electrocardiograph leads (I, aVR, V1, V5) recorded in eight healthy people relaxing in a semirecumbent position.**

***Main outcome measures*—Manual measurement of QT interval in 512 electrocardiograms (eight subjects × four leads × eight presentations × two repeats) by each of four cardiologists.**

***Results*—QT intervals measured were significantly longer with greater amplifier gain: by 8 ms for a doubling of gain ($p < 0.005$), equivalent to a doubling of T wave height. QT intervals measured were significantly longer at slower paper speeds: by 11 ms when paper speed was reduced from 100 to 50 mm/s ($p < 0.001$) and by 16 ms when speed was further reduced from 50 to 25 mm/s ($p < 0.001$). Neither the presence of noise nor the presence of a second QRST complex altered the mean QT measurements. There were consistent differences in the measurements between cardiologists, amounting to a maximum mean difference of 20 ms.**

***Conclusions*—Manual measurement of QT interval is significantly affected by the paper speed used to plot the electrocardiogram and by electrocardiogram gain, and hence also T wave amplitude. Manual QT measurement also differed consistently with different cardiologists.**

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Abnormalities of cardiac repolarisation may identify patients at risk of lethal arrhythmias.[1–3] Simple measurement of QT interval is pivotal for the diagnosis of long QT syndrome, is essential in monitoring the wanted and unwanted effects of cardioactive drugs, and may help identify high risk survivors of acute myocardial infarction. Direct repolarisation measurements, obtained during cardiac electrophysiological procedures and at open heart surgery, have correlated with QT features and with the configuration of the T wave on the surface electrocardiogram.[4,5] This has provided a scientific basis for the measurement of QT dispersion on the surface electrocardiogram to detect abnormalities in arrhythmogenic repolarisation.[6–8]

Despite the growing importance of the QT interval there is no standard method for its measurement. As even small changes in QT interval seem to have clinical relevance, consistent and accurate measurement of the QT interval is essential. Accurate measurement should enable reliable identification of small changes in QT interval related to time, drug treatment, or to differences between leads. Traditionally the QT interval is measured manually, although a global QT value for 12 lead electrocardiograms is offered by many computerised recorders. With growing importance of concepts such as QT dispersion, accurate automatic multilead measurement would have great use. Automated QT measurements use a defined algorithm and so offer consistency, but may produce values for QT that differ from those made manually by experienced cardiologists. Automatic techniques include those involving threshold measurements,[9,10] or a combination of threshold and T wave slope measurements.[11–13] As yet there is reluctance to use these techniques; few have been validated, and little comparative information is available. Mirvis reported the need to edit 15% of automated QT measurements.[11] Even with manual measurement researchers were rarely confident enough to measure all QT intervals, with no measurement being attempted in between 3%[6] and 40%[14] of leads. The manual method generally remains the technique of choice for important clinical studies despite paucity of knowledge regarding its accuracy, and the T wave features that influence accuracy.

The aim of this project was to determine how manual measurement of QT interval is influenced by noise, recording paper speed, amplifier gain, and the presence or absence of a second QRST waveform to provide information on the RR interval.

Methods

ELECTROCARDIOGRAPHIC RECORDINGS

Electrocardiographic recordings were obtained from eight healthy people who relaxed semirecumbent for a few minutes before recordings were made. They were asked to lie still to avoid muscle movement. Four leads I, aVR, V1, V5 were recorded. Also, in one person, a sample of muscle noise, uncontaminated by the electrocardiogram, was recorded from two closely spaced electrodes. All electrocardiograms and the sample of muscle noise were amplified with a gain of 1000 and frequency bandwidth of 0·05 to 100 Hz. They were then recorded directly to a computer by means of a 12 bit analogue to digital converter (DASH 16) with a resolution of 2·4 μV and a sampling rate for each channel of 500 Hz.

ELECTROCARDIOGRAPHIC PRESENTATIONS

The electrocardiograms were printed to paper with a Laserjet III printer that had a resolution of 118 dots/cm. They were printed with different timebases and amplitudes to simulate different paper speeds and amplifier gains. The muscle noise was scaled to give an SD of 10 μV (noise level 1) or 20 μV (noise level 2), and was superimposed on the electrocardiograms before printing to create the noisy electrocardiograms.

Each lead in each subject's recording was presented on paper in eight different formats (fig 1). The formats were as follows: (*a*) 10 mm/mV, 50 mm/s; (*b*) 10 mm/mV, 50 mm/s, 10 μV noise; (*c*) 10 mm/mV, 50 mm/s, 20 μV noise; (*d*) 10 mm/mV, 100 mm/s; (*e*) 10 mm/mV, 25 mm/s; (*f*) 5 mm/mV, 50 mm/s; (*g*) 15 mm/mV, 50 mm/s; (*h*) 10 mm/mV, 50 mm/s, single QRST complex.

All presentations except one showed at least two QRST complexes. All presentations were printed twice for each of four cardiologists who undertook the measurements. In total, each cardiologist manually measured 512 QT intervals (eight subjects × four leads × eight presentations × two repeats).

The sequence of the 512 electrocardiograms was randomised with a Graeco-Latin square technique. Four complete sets were printed with a different starting point in the randomisation for each set.

MEASUREMENTS

Each set of 512 electrocardiograms was presented to the four independent cardiologists. The cardiologists, all with considerable experience in QT measurement, were neither told the purpose of the study nor how the electrocardiograms had been obtained, and they were not involved in the design of the study. They therefore measured each QT without knowledge of its possible relation to other QTs in the series. No discussion between the cardiologists was allowed. They were asked to start at the first electrocardiogram and work through all 512 in a single measurement session. They used a pen with a thin black tip to indicate on the first complex the start of the Q wave and the end of the T wave by short lines vertically intersecting the electrocardiogram. All cardiologists used the same definition for QT, measuring from the onset of the QRS to the end of the T wave at its return to the TP baseline. As measurements were of the complete QT interval, any error in determining the position of the start of the Q wave was included in the measurement of QT.

The manually marked QTs were then measured with a digitising tablet (SummaSketch III, Summagraphics) connected to a personal computer. In a preliminary study this digitising technique gave a repeatability error (SD) of 0·14 mm, equivalent to 2·8 ms at a paper speed of 50 mm/s. For each electrocardiogram, the marked start of Q and marked end of T were digitised by a single researcher. Also, the measurements of one cardiologist were digitised by a second researcher to detect any mean errors in the digitising procedure (mean difference 0·06 ms). None of the cardiologists undertook the digitising.

ANALYSIS

Analysis of variance was used to assess overall differences between subjects, presentations, leads, and cardiologists. Only when significant differences were discovered was further analysis performed with Student's *t* test.

Results

OVERALL ANALYSIS

There were highly significant differences between subjects ($p < 0·0001$), electrocardiographic presentations ($p < 0·0001$), leads ($p < 0·0001$), and cardiologists ($p < 0·0001$).

ELECTROCARDIOGRAPHIC PRESENTATION

Figure 2 shows a summary of the results for each of the four cardiologists for the effects of noise, paper speed, gain, and the availability of only a single QRST complex.

There were no significant differences in the measurement of QT with increasing noise up to the level of 20 μV used in this study. The variability (SD) of repeat measurements increased from 9·5 ms (no added noise) and 9·8 ms (10 μV noise) to 10·8 ms (20 μV noise). This figure was the second highest repeatability error encountered in the study.

There were significant changes in QT measurement with different paper speeds. The QT interval lengthened by 11 ms between 100 and 50 mm/ms ($p < 0·001$), and by a further 16 ms between 50 and 25 mm/s ($p < 0·001$). The highest repeatability error in the study was with measurements at 25 mm/s and equalled 15·8 ms, in comparison with 8·8 ms and 9·5 at 50 mm/s.

There were significant changes in QT measurement with amplifier gain. The QT interval increased by 8 ms between 5 and 10 mm/mV ($p < 0·005$), and by a further 5 ms between 10 and 15 mm/mV. Although this figure was not significant it was consistent with the 8 ms error resulting from doubling the amplifier gain from 5 to 10 mm/mV and hence also from a doubling of the height of

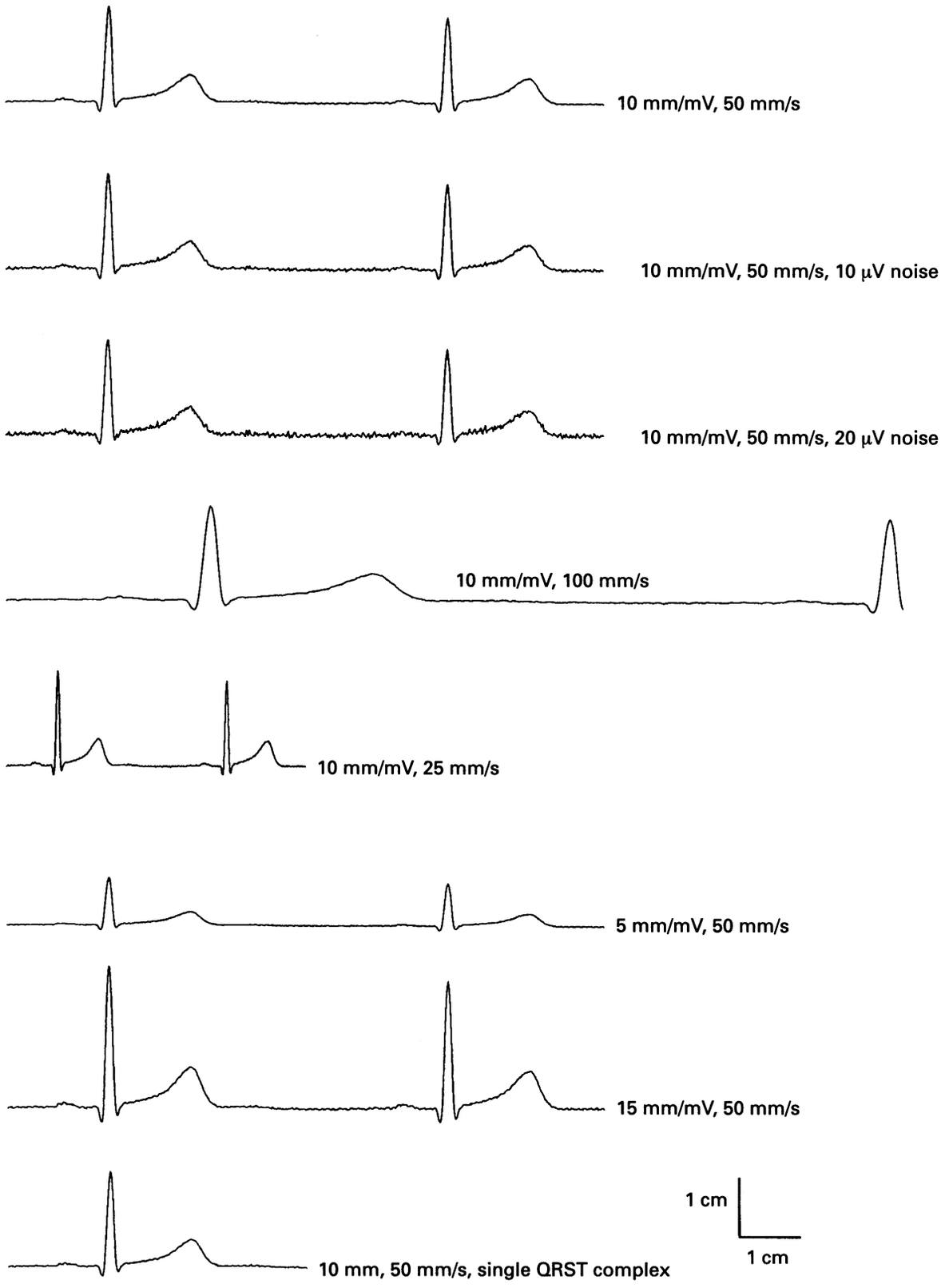

Figure 1 Example of the eight electrocardiographic presentations taken from a single lead (V5) from a single subject.

the T wave. The repeatability error changed little with gain, equalling 9·8 at 5, 9·5 at 10, and 9·5 mm at 15 mm/mV.

There was no significant difference in QT measurement between those presentations with a second QRST and those with only a single QRST.

ELECTROCARDIOGRAPHIC LEADS

There was significant differences between leads. Also, there was a tendency for increasing QT interval to relate to increasing height of the T wave. The mean values were as follows: I, 393 ms, 0·21 mV; aVR, 403 ms, 0·31 mV; V1, 404 ms, 0·44 mV; V5, 409 ms, 0·44

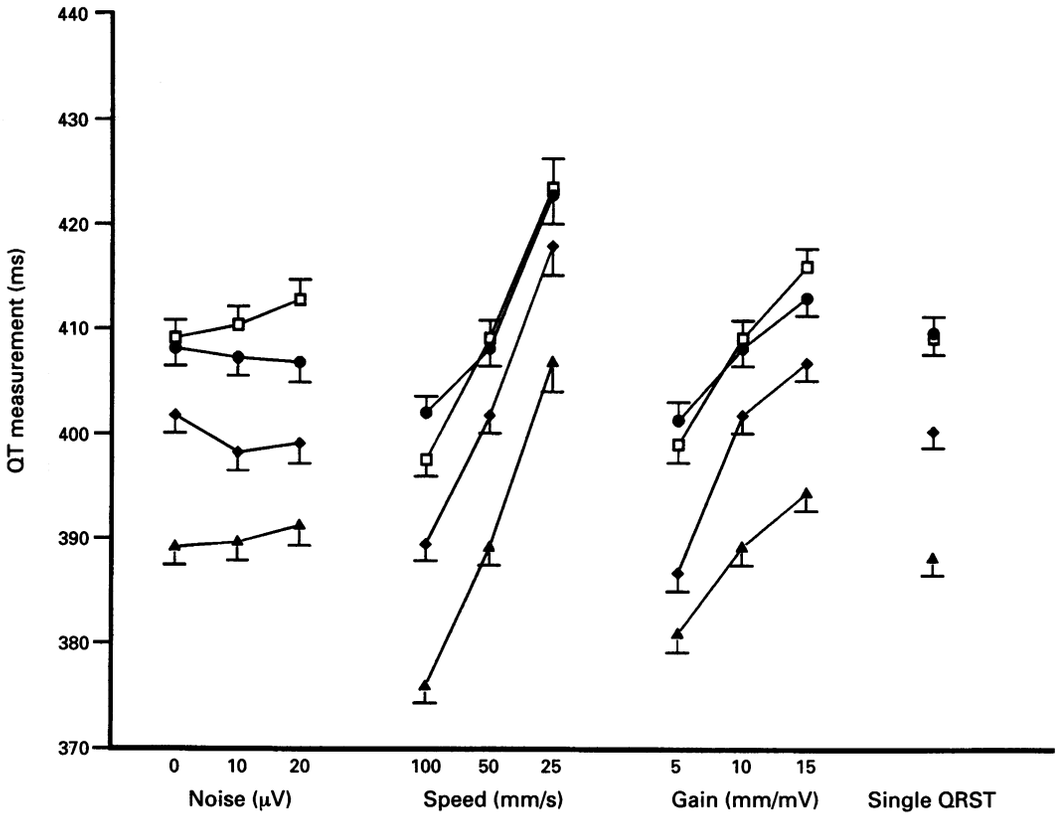

Figure 2 Results of the mean QT measurements for each cardiologist for all electrocardiographic presentations. The reference electrocardiogram has no added noise, 50 mm/s speed, and 10 mm/mV gain. The best estimate of repeatability error for each cardiologist and each electrocardiographic presentation (from the two repeats of each electrocardiogram) are given as error bars for SEMs.

mV. When the relation between QT measurement and height of the T wave was assessed in the individual subjects, the mean relation was equivalent to an increase of 7 ms in QT interval for every doubling in T wave height. Some subjects had a small range of T wave heights, and when the analysis was restricted to the four of the eight subjects who had at least a threefold range in T wave heights between leads, QT interval increased by 10 ms for a doubling in T wave height.

CARDIOLOGISTS

There were significant and consistent differences between cardiologists (fig 2). The mean QT over all the electrocardiograms for each cardiologist was 389·5, 408·0, 400·9, and 409·7 ms. The greatest mean difference was 20·2 ms.

Discussion

This study has quantified the errors associated with the manual measurement of the QT interval. Because it was necessary to print a number of versions of each electrocardiogram to simulate the different paper speeds, gains and noise, the electrocardiograms could not be printed on standard paper. Also, to ensure consistency in approach, the cardiologists were asked to mark the recordings with a pen. This technique therefore differed a little from standard QT measurement, and from the technique described by our group for measuring QT dispersion. Nevertheless, the basic principles examined in this study are common to the various techniques of QT measurement.

Measurements were not influenced by low levels of noise. Also, it seemed that information that might be deduced from the RR interval when two QRST complexes were printed was not used, at least in these normal electrocardiograms. The mean difference found between cardiologists is similar to that reported by Ahnve,[15] who when comparing the QT measurements of nine different researchers, found a maximum mean difference of 27·9 ms.

The QT measurements made by the cardiologists were significantly influenced by different paper speeds and gains. The QT measurements were consistently longer when the amplitude of the tail of the T wave was greater (and vice versa). This same relation was seen in the variation of QT interval with T wave height over the different leads, raising the question of how much was due to variation in T wave height and how much to genuine regional differences in repolarisation. Although this study was not designed to answer this question, the data suggest that in these normal subjects a substantial part of their measured QT dispersion could be a result of variation in T wave height.

If variation in the amplitude of the T wave contributes to measurement of QT dispersion, this could have important implications at a time when QT dispersion seems of considerable clinical importance. In practice, however, many of the published figures for clinically significant QT dispersion lie well above the errors encountered in this study. Day *et al* discovered a mean QT dispersion of 185 ms in patients with arrhythmogenic long QT intervals and 60 ms in patients with a long QT interval due to sotalol.[3] Cowan *et al* reported QT dispersion values of 73 ms for

inferior myocardial infarction, 70 ms for anterior myocardial infarction, and 48 ms for a control group of patients admitted for general surgery and with no history of heart disease.[6] Also, QT measured from the lead with the largest T wave amplitude gave a reasonable approximation to the maximum QT from all leads.[6] This accords with the results of our study.

In this study, a threefold increase of T wave height, equivalent to a range of T wave heights from 0·1 to 0·8 mV, would result in mean errors of 3 x 8 ms = 24 ms. Such a range in T wave height could easily be found in a clinical study. In some studies, however, QT measurement was not attempted when the T waves were small. In such a situation, the range in T wave heights might be limited to a doubling of T wave height, equivalent to a mean error of 2 x 8 ms = 16 ms. Our results suggest that depending on the range of T wave heights, QT dispersion values approaching 16 or 24 ms should be interpreted with care.

In conclusion, some important practical recommendations results from this study. If more than one cardiologist is to measure QT intervals, each must make all measurements, or the study must be carefully constructed and randomised. Different paper speeds should not be used. Small differences in QT interval and small ranges of dispersion must be interpreted with great care, taking into account errors in the measurement of QT associated with different T wave heights.

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