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The effects of noise on computerized electrocardiogram measurements

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Abstract Computerized measurements provide objective and reproducible assessments of the electrocardiogram (ECG). These measurements may be affected by noise or other lead quality issues. The effects of noise on the repeatability of computer-measured PR interval, QRS duration, QT interval, P/QRS/T axes, and ST levels were examined.

Methods: The 125 ECGs of the Common Standards for Quantitative Electrocardiography (CSE) measurement database (MO1 series) were merged with records from the MIT Noise Stress Test database. For each CSE ECG, 720 unique noise ECGs were created, for a total of 90 000 noisy ECGs. Computerized measurements from the noisy ECGs were compared to the original ECG measurements. The repeatability of the measurements was assessed as a function of a lead quality score.

Results: The repeatability of the measurements was found to be in excellent agreement with the original ECG measurements when the noise level was no worse than that of the original ECGs. Noise did not introduce any bias to the measurements, although not surprisingly, the variation of the errors increased as the lead quality degraded.

Keywords: ECG; Measurements; Noise; QT; Reproducibility

Introduction

Computerized measurements provide objective and reproducible assessments of the electrocardiogram (ECG). Accurate measurements of intervals, axes, and ST levels are an important first step in the overall ECG interpretation for computerized interpretation programs and for the human electrocardiographer. Errors in these measurements can lead to increased errors in the ECG interpretation.[1] The accuracy of these measurements can be adversely impacted by noise in the ECG signal. Computerized measurement programs that make measurements on a representative beat generated by some type of signal averaging method have repeatedly been shown to perform better and are generally more stable in noise conditions.[2-4] The GE Marquette 12SL ECG Analysis Program (GE Healthcare, Wauwatosa, WI) forms a representative beat, referred to as the "median complex," from which global measurements such as PR interval, QRS duration, QT interval, and the P, QRS, and T axes, and per-lead measurements such as ST levels are calculated.

The objective of the present study was to present a repeatable methodology for the creation of "noisy" ECGs for the assessment of robustness of computerized measurements. This study shows the effects of noise on the accuracy and repeatability of ECG measurements and presents a method for quantification of the noise.

The 125 ECGs of the Common Standards for Quantitative Electrocardiography (CSE) measurement database (MO1 series) were "merged" with the muscle artifact and baseline wander records of the MIT Noise Stress Test (NST) database such that the NST records were divided into 10-second segments and added to the CSE record ECG signals. For each CSE ECG, 720 unique noise ECGs were created, for a total of 90 000 noisy ECGs. The ECGs were analyzed, and the measurements of the noisy ECGs were compared to the original ECG to quantify the repeatability of the measurements in the face of noise. For the PR interval, QRS duration, and QT interval, the measurements of the original and noisy ECGs were compared to the CSE "gold standard" reference measurements. In addition, an objective lead quality algorithm assessed the overall quality of the ECG. The repeatability of the 12SL measurements was assessed as a function of the noise level in the ECG, as quantified by a lead quality algorithm.

Methods

Electrocardiogram sources

The ECGs and the noise signals came from industry-standard, publicly available databases. The 125 ECGs of the

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MO1 series of the CSE Measurement Database were used as the reference ECGs. The noise signals came from the muscle artifact and baseline wander records of the MIT-BIH Noise Stress Test Database.

The CSE Measurement Database consists of 250 ten-second 12-lead resting ECGs.[5,6] The CSE database is divided into 2 series: MO1 and MO2. For the MO1 series, reference or gold standard measurements of PR interval, QRS duration, and QT interval are available for 123 of 125 ECGs (measurements are not supplied for records MO1_067 or MO1_070 for the stated reason that these are paced ECGs). Reference measurements for the MO2 series are not distributed and are kept secret by the CSE for testing purposes. The CSE ECGs were acquired and stored at a sample rate of 500 samples per second, with no filtering or any other signal preprocessing performed. The 125 ECGs of the MO1 series were used for this study. A subset of 100 of those ECGs are specified for use in electrocardiograph measurement accuracy testing by international standard IEC 60601-2-51.[7]

The Massachusetts Institute of Technology–Beth Israel Hospital Noise Stress Test Database (MIT-BIH NST Database)[8,9] consists of three 30-minute 2-channel noise records. This database is specified for the analysis of the robustness of ambulatory ECG analysis by the AAMI standard EC38.[10] The noise recordings were made using physically active volunteers and standard ECG recorders, leads, and electrodes; the electrodes were placed on the limbs in positions in which the subjects' ECGs were not visible. The 3 noise records were assembled from the recordings by selecting intervals that contained predominantly baseline wander (in record "bw"), muscle artifact (in record "ma"), and electrode motion artifact (in record "em"). It should be noted that there is a fair amount of noise-type crossover in these records; for example, record bw also contains sections of muscle artifact and electrode motion artifact. The muscle artifact and baseline wander records were used for this study.

Creation of noise ECGs

The NST records were resampled to 500 samples per second and partitioned into 180 ten-second segments. For each segment, one channel of the noise recording was directly added to leads I, II, V1 to V6 (ie, the input signals to the 12SL program) of the reference (CSE) ECG. Further, because each noise record contained 2 channels, 2 noise ECGs were created for each 10-second segment, generating 360 noise ECGs for each original CSE ECG. This process was repeated for both NST records (muscle artifact and baseline wander). Thus, a total of 720 unique noise ECGs were created for each original CSE ECG. Given the 125 original CSE ECGs, a grand total of 90 000 noise ECGs were created. Fig. 1 shows an example of typical muscle artifact and baseline wander added to 1 ECG.

No attempt was made to simulate the noise being introduced in any one or any particular combination of electrodes, nor to account for the reduced amplitude or inverted phase that would otherwise have been observed in the V leads if the noise had truly been injected only in the limb electrodes. That is, the noise was added directly to the "lead" signals, not to the "electrode" signals. This is actually a more rigorous exercise of a program's ability to analyze an ECG in the presence of noise than if injection of noise into a particular electrode was simulated.

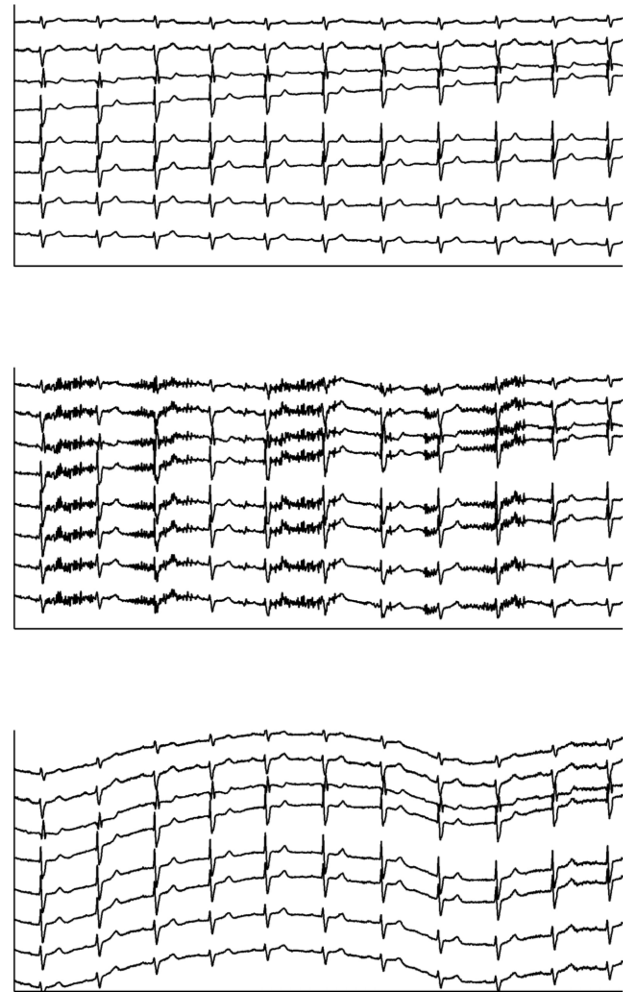

Fig. 1. Electrocardiogram MO1_001 (top), with segment from muscle artifact record added (middle), and with segment from baseline wander record added (bottom). Eight leads are displayed: I, II, V1 to V6.

Electrocardiogram processing

The 125 original and 90 000 noise ECGs were high-pass filtered using a 0.16-Hz high-pass (baseline roll) filter. The filter was applied in both the forward and reverse directions, resulting in linear-phase response and no ST-segment distortion. The ECGs were then processed by the GE 12SL ECG Analysis Program (version 21). The outputs of 12SL used in this analysis include the following:

- Ventricular rate, PR interval, QRS duration, QT interval, and the P, QRS, and T axes.
- Per-lead ST levels at STJ (J-point), STM (J-point + 1/16 of average RR interval), STE (J-point + 1/8 of average RR interval).
- Overall ECG and per-lead quality indicators as described below.

Leads I, II, and V1 to V6 of each ECG were analyzed for muscle tremor, baseline wander, powerline (AC) interfer-