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REVIEW TOPIC OF THE WEEK

# Computer-Interpreted Electrocardiograms

## Benefits and Limitations

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**ABSTRACT**

Computerized interpretation of the electrocardiogram (CIE) was introduced to improve the correct interpretation of the electrocardiogram (ECG), facilitating health care decision making and reducing costs. Worldwide, millions of ECGs are recorded annually, with the majority automatically analyzed, followed by an immediate interpretation. Limitations in the diagnostic accuracy of CIE were soon recognized and still persist, despite ongoing improvement in ECG algorithms. Unfortunately, inexperienced physicians ordering the ECG may fail to recognize interpretation mistakes and accept the automated diagnosis without criticism. Clinical mismanagement may result, with the risk of exposing patients to useless investigations or potentially dangerous treatment. Consequently, CIE over-reading and confirmation by an experienced ECG reader are essential and are repeatedly recommended in published reports. Implementation of new ECG knowledge is also important. The current status of automated ECG interpretation is reviewed, with suggestions for improvement. (J Am Coll Cardiol 2017;70:1183–92) © 2017 by the American College of Cardiology Foundation.

The first attempts to automate electrocardiogram (ECG) analysis go back to the late 1950s (1,2), and it was soon expected that digital computers would have an important role in ECG processing and interpretation (3). Despite technical developments, the clinical use of the computerized ECG remained initially limited because of the lack of agreement on definitions of waves and common measurements, standardized criteria for classification, and terminology for reporting (4). To address these difficulties, efforts to propose standards and recommendations were developed, both in Europe and in the United States, to establish an international standard for computerized interpretation of the ECG (CIE) (5). The goals were to reduce the wide variation in wave measurements obtained by ECG computer programs and to assess and improve the diagnostic classification of ECG interpretation (6) so that similar measurements and diagnostic results could be obtained independent of the computer program used (4). However, despite all these efforts and advances in the field, an international accepted standard is still missing (5).

## GENERAL COMMENTS ABOUT TECHNICAL ASPECTS

For digital ECG programs providing diagnostic interpretation, several technical aspects have to be considered:

1. Signal processing, including acquisition, conversion from analog to digital signals, and filtering to eliminate noise (e.g., myopotentials, movement artifacts, baseline wandering linked to respiration). Correct filtering is a fundamental step, as it can dramatically alter the final processed signal (5,6).
2. In the majority of automated systems, all ECG leads are now recorded simultaneously. Construction of representative template complexes (dominant complexes) excluding premature beats allows formation of an average complex for each lead (6).

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**ABBREVIATIONS AND ACRONYMS**

**AF** = atrial fibrillation

**CIE** = computerized interpretation of the electrocardiogram

**ECG** = electrocardiogram

**LVH** = left ventricular hypertrophy

**STEMI** = ST-segment elevation myocardial infarction

3. Waveform recognition, with precise determination of onset and offset of the different waves (P-wave, QRS complex, T-wave). The temporal alignment and superimposition of the representative complex for each lead offers more accurate labeling of wave onset and offset (6).
4. Measurements of intervals (PR, QRS, QT) and amplitude parameters. When performed, global interval measurements are associated with higher values than single lead measurements because they remove isoelectric intervals present in each of the single leads (7–9). This process is simple and straightforward when the ECG signal is registered in normal sinus rhythm, but it may become very complex in the presence of atrial arrhythmias (5), requiring time-domain or spectral analysis for recognition and discrimination of rapid electrical atrial activity. Manufacturers' algorithms for determining onset and offset of waves vary, and are the cause of recurrent differences in QRS duration and of differences in QT interval measurements (10–12).
5. In a recent study, 4 different current digital electrocardiographs were studied as to their automated measurement of RR, PR, QRS, and QT interval duration in 600 ECGs. It included 200 ECGs during QT interval studies in normal subjects, 200 ECGs in normal subjects during the peak of moxifloxacin administration (known to modestly prolong the QT interval), and 200 patients with genotyped variants of long QT syndrome (8). Measured intervals and durations show small, but statistically significant group differences between manufacturers (8). Mean absolute differences between algorithms were similar for QRS duration and QT interval in normal subjects, but were significantly larger in patients with long QT syndrome (8).

   Amplitude measurement discrepancies were less frequently reported, but day-to-day variability in amplitude measurements have been described, leading to significant differences in voltage measurements and, consequently, in computer diagnoses (5–10). Despite progress in the development of the various algorithms, differences in measurements results persist, and the call for standardization and recommendations for definitions of waves and references, already initiated in the 1970s, still remains incompletely answered (10,13). Statements using precise measurement of ECG amplitudes and durations can approach experienced readers in sensitivity, specificity, and reproducibility (14). However, statements that depend on waveform configuration (e.g., repolarization) and relationship between waveforms (e.g., irregular P waves, atrioventricular conduction disturbances) (**Figure 1**) may be less accurate, as the computer reading the ECG does not have the visual pattern recognition skills of a human being (14,15).
6. Interpretation using diagnostic algorithms to the processed ECG. These algorithms are proprietary, and may perform differently when applied to ECG signals processed by different methods (6). Measurement differences among various standard ECG systems may be sufficiently large to alter diagnostic conclusions (4). This may have clinical consequences and, for example, interfere with the selection of candidates for cardiac resynchronization therapy, as QRS duration is the main determinant for device implantation in these patients (11,12).
7. Finally, data compression, transmission, and archiving are also important aspects of digital processing (5).

## ALGORITHM ACCURACY

Algorithm accuracy may vary according to both the manufacturer's automated program and the level of the participating ECGs' over-readers. Indeed, these algorithms are usually tested in comparison with the diagnosis of expert physicians, cardiologists, electrophysiologists, or using a consensus of experts (6), considered to be the "gold standard." Furthermore, ECG interpretation is a mixture of both subjective and objective aspects, where even experienced cardiologists or experts can disagree, resulting in significant interobserver variability (16). Additionally, ECG databases used in testing computer programs may insufficiently represent the overall population; in fact, they should be sufficiently large and diverse to contain all possible clinical diagnoses to mirror daily medical practice (5). Direct comparative evaluation of the performance of commercially available CIE programs has never been performed, mainly due to the reluctance of the manufacturers who own the various algorithms. From this perspective, more collaboration among the various manufacturers would be desirable (**Central Illustration**).

**CURRENT STATUS OF CIE.** In 1991, the first systematic assessment of computer programs compared the performance of 9 electrocardiographic computer programs with that of 8 cardiologists in interpreting ECGs in 1,220 clinically validated cases of various disorders (17). All together, the median total accuracy