The Five-Minute ECG

An in-depth analysis of the new alternative to traditional 10-second ECG recordings

Given the considerable biological variability of electrocardiograms and the additional variability associated with their acquisition and analysis, a 10-second ECG recording may not be an appropriate measure of a patient's true electrocardiographic state. ■ ■ ■ A longer recording may be a more effective approach given its ability to identify irregularities that cannot be detected using shorter, isolated readings. ■ ■ ■ This paper focuses on the pros and cons of using a five-minute ECG in clinical and research settings compared to the traditional 10-second ECG.

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RESEARCH BEYOND RESULTS

The traditional electrocardiogram (ECG) is a 10-second recording, most often displayed in a three-by-four format, which provides 2.5 seconds of waveform data for each lead. Given the considerable biological variability of every aspect of the ECG, which occurs on a beat-to-beat basis and over longer cycle times, and the often more striking variability associated with acquisition and processing of the body-surface signal, it is clear that the traditional ECG cannot represent the true "electrocardiographic state" of the patient. A five-minute recording, if effectively analyzed and displayed, may be a reasonable compromise between the need to complete the test quickly and the need for accuracy. The purpose of this article is to consider advantages and disadvantages of the five-minute recording, based upon recent experience with the acquisition and analysis of five-minute recordings of 12-lead ECGs.

PRODUCING A FIVE-MINUTE RECORDING

Most modern 12-lead diagnostic electrocardiographs can, in fact, make five-minute recordings, or long recordings of various durations. All that is required is adequate electronic storage and on/off functionality intended for longer data capture. There are also numerous devices available that perform multi-lead recordings up to several days in duration for the purpose of arrhythmia and ischemia monitoring. However, few diagnostic electrocardiographs provide a means for using the extended data to enhance 12-lead ECG diagnostic statement capabilities. There is only one such device currently in clinical use – the Spaulding Electrocardiograph.

ANALYZING A FIVE-MINUTE RECORDING

The discussion below describes analyses performed by the Spaulding Electrocardiograph. Of course, other analytical approaches are possible and anticipated.

The *Summary ECG* is a simulated 10-second ECG that we derive from the five-minute ECG recording. A median or representative beat is created by averaging the PQRST waveforms of all normal, noise-free beats recorded during the five-minute period, separately for each of the 12 leads. These medians are then linked together with an inter-beat cycle length equal to the average heart rate during the recording. This results in a very clean-looking ECG with the beats within each lead looking identical. The summary ECG is then used to make interval measurements, either by a computer algorithm or by manual annotation (or both).

Assessment of Arrhythmias is made possible by longer recordings. Arrhythmias are identified and quantified using existing diagnostic and beat-categorization software, or the recordings can be reviewed by hand at a variety of speeds and time compressions.

Variability Assessments are performed on the roughly 300 beats recorded over five minutes. Simple descriptive statistics for RR, PR, QRS, QT and QTc include mean, median, standard deviation, minimum and maximum. Heart rate variability (HRV) is commonly evaluated either over 24 hours or over five minutes. The five-minute representation of HRV has been shown to correlate fairly well with daylong HRV results, though the ultra-low frequency band cannot be assessed. Variability of QTc is also calculated using indices that have been tested for their prognostic value. The variability of T-wave morphology is measured using direct algorithmic amplitude and duration measurements and eigenvector-based analyses of wave shape change.

Other Assessments performed include a listing of all diagnostic statements derived from each of the thirty 10-second ECG segments captured over five minutes (see **Figure 5** and **Figure 6**) and signal averaging for measurement of QRS duration and late potentials. Many other possibilities exist.

ADVANTAGES OF A FIVE-MINUTE RECORDING

The *Summary ECG*: **Figure 1** shows an example of a Summary ECG. As you would expect, the tracing is very clear, the inter-beat cycle length is precisely consistent and the PQRST waveforms are identical in each lead. **This type of ECG display is extremely easy to view and interpret.** The clean waveform is especially suited for high-resolution annotation, as shown in **Figure 2**.

In addition to the clarity of the ECG, the ease of viewing it and the ability to annotate it more accurately, the waveform is based on more real data and is therefore more robust and reliable. In essence, the representative beat is **constructed from about 300 beats rather than the usual 10 beats.**

Figure 1: Example of a Summary ECG. The higher magnification inset at lower right shows that the waveforms in lead 2 are clean and identical.

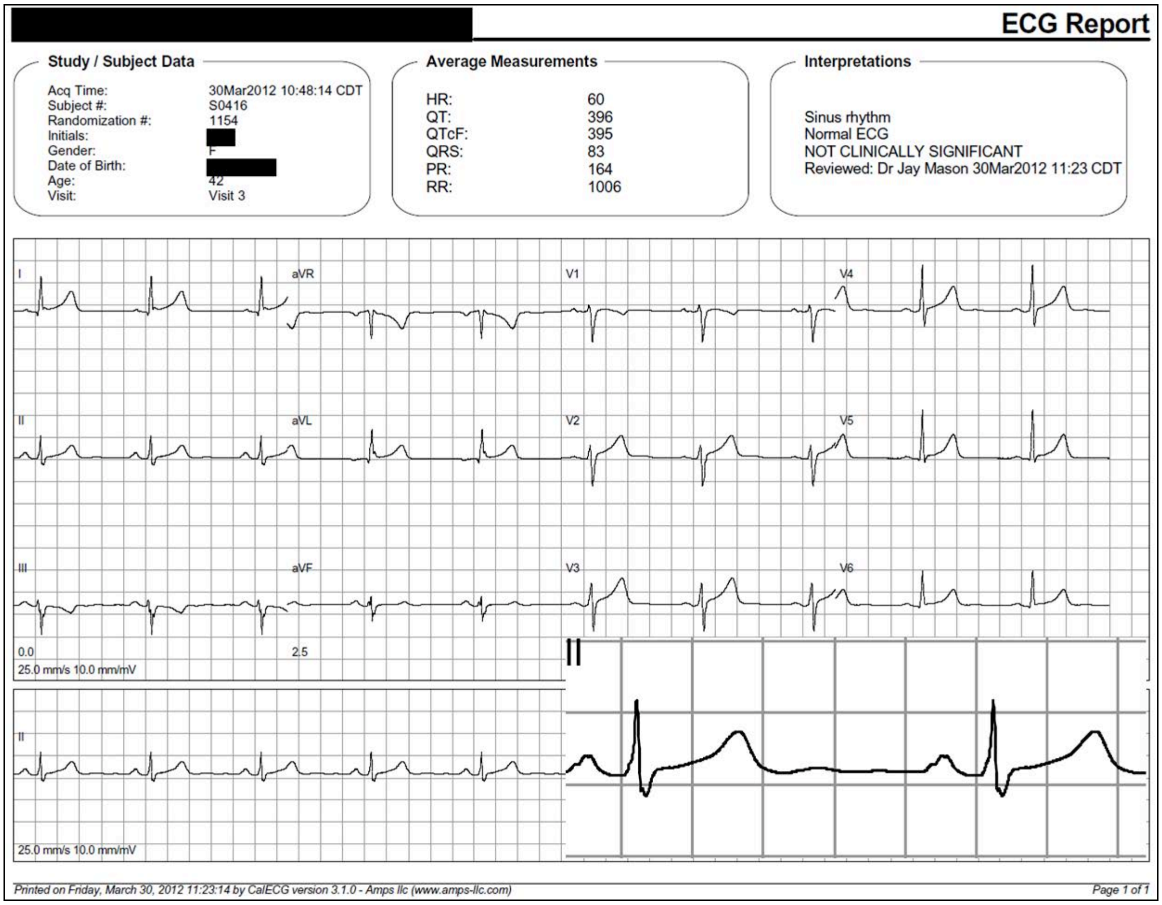
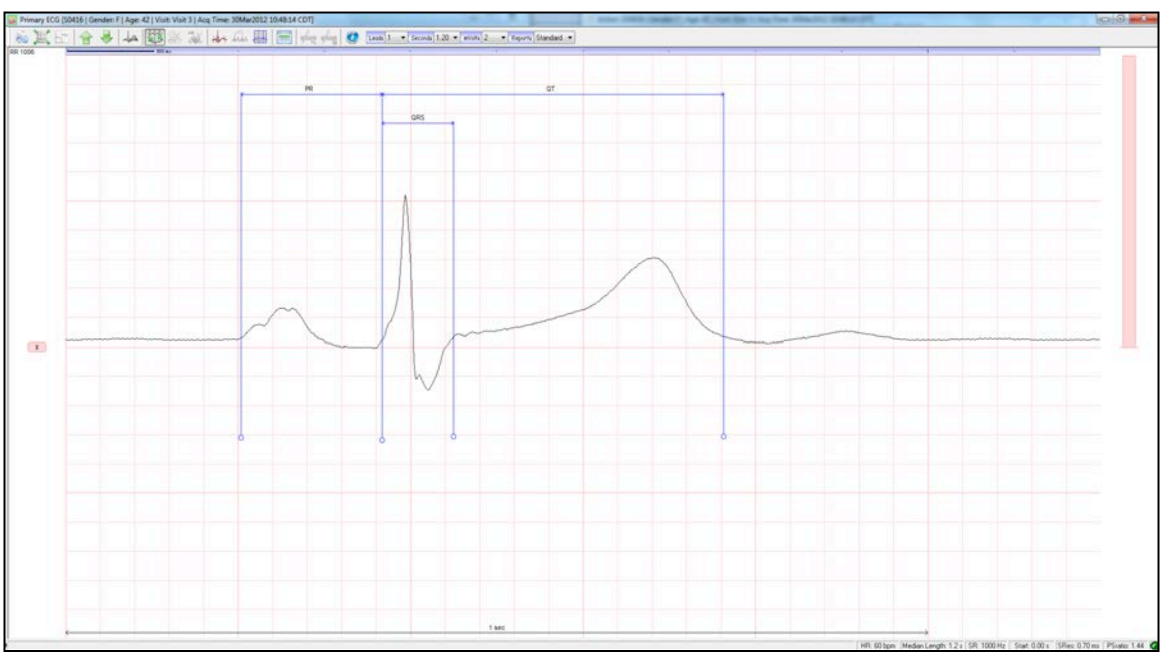


Figure 2: Lead 2 median beat from the patient above viewed in CalECG (AMPS, LLC) for interval measurements.



ASSESSMENT OF ARRHYTHMIAS

Even when frequent, arrhythmias are usually not captured on the traditional 10-second ECG. This is probably the greatest shortcoming of routine electrocardiography today. **The five-minute recording greatly increases the opportunity to detect arrhythmias.** **Figure 3** provides an example of ventricular ectopy that was missed during the initial 10 seconds of a traditional recording, but clearly present during a longer recording (**Figure 4**).

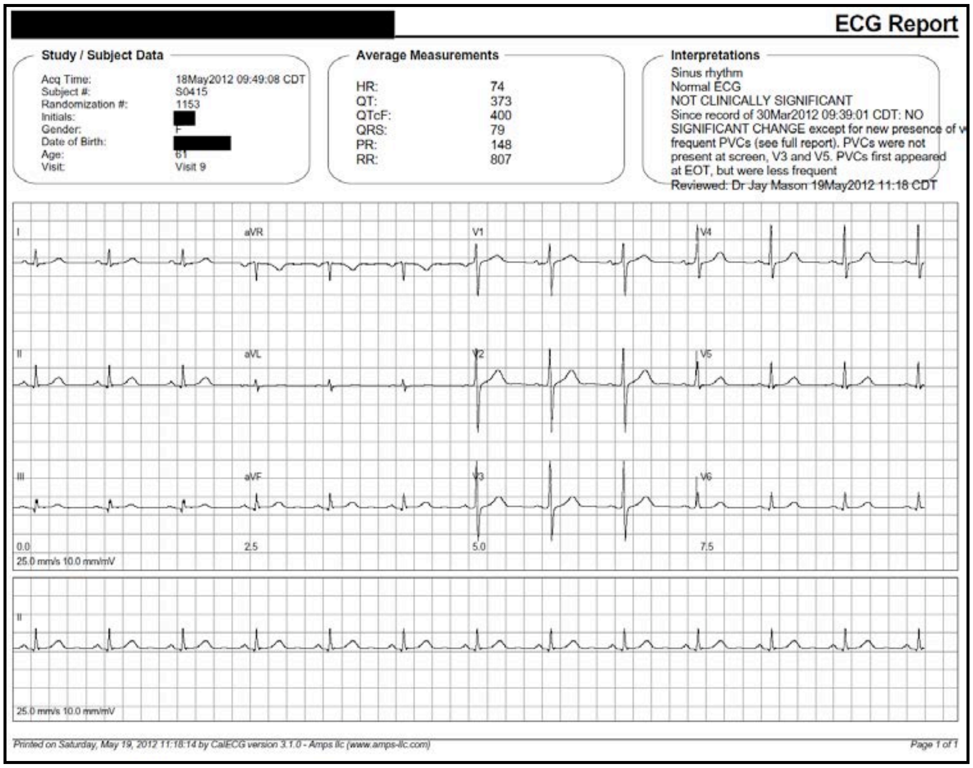


Figure 3: Summary ECG showing no ventricular ectopy.

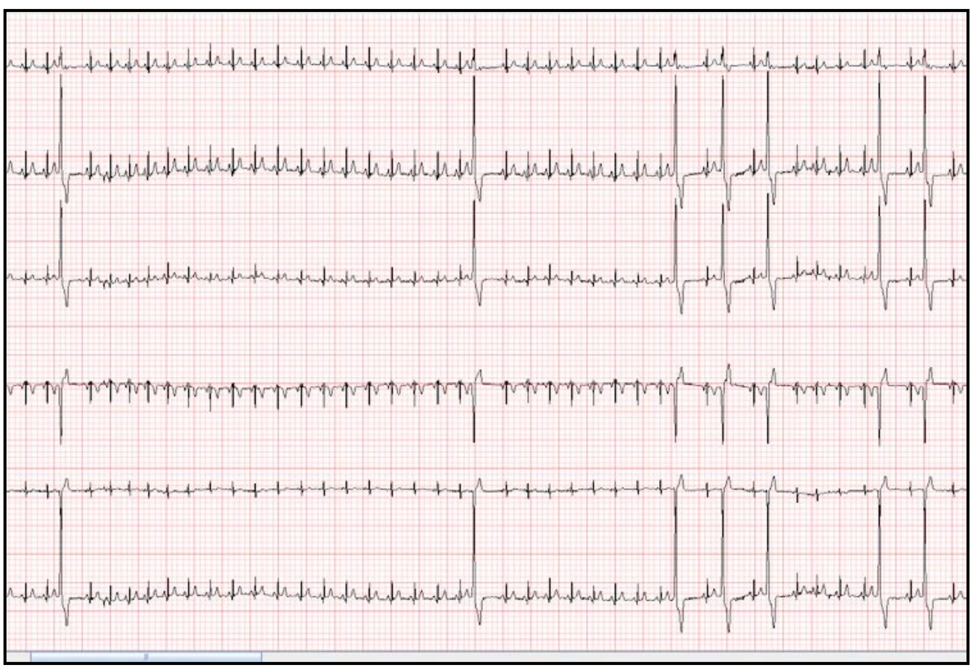


Figure 4: Ventricular ectopic beats detected by a five-minute recording.

The full report of the five-minute recording includes a listing of diagnostic statements and their frequency of occurrence during each consecutive 10-second ECG (**Figure 5**). Note that one PVC was present on 12 of the 30 consecutive 10-second periods (“Sinus rhythm with PVCs”) and on two of the 30 more than one PVC was present (“Sinus rhythm with frequent PVCs”). Thus, there would have been less than a 50% chance (14/30) of detecting PVCs in this patient with a single 10-second ECG randomly recorded during the five-minute period. Further, if these recordings had been done by Holter and had ECGs been extracted at this five-minute time point using a selection strategy that identifies, for example, the three 10-second periods with the most regular rhythm and preceding rate stability, there would have been no chance of detecting the ectopy.

Based on current experience with the five-minute ECG, detection of **many arrhythmias, not captured on the traditional 10-second ECG, were detected**, including ventricular ectopy, ventricular tachycardia, supraventricular ectopy, supraventricular tachycardia, sinus pauses and second-degree AV block.

Figure 5: Diagnostic statement list for the patient with PVCs above.

6 Diagnostic Statements

15/30 - Sinus rhythm
16/30 - Normal ECG
12/30 - Sinus rhythm with PVCs
12/30 - Borderline ECG
2/30 - Sinus rhythm with frequent PVCs
2/30 - Abnormal ECG
1/30 - Sinus arrhythmia

Figure 6: Diagnostic statements listing showing variable criteria for inferior infarction.

5 Diagnostic Statements

29/30 - Sinus rhythm
6/30 - Normal ECG
1/30 - Inferior infarct - age undetermined
24/30 - Abnormal ECG
23/30 - Possible inferior infarct - age undetermined
1/30 - Sinus arrhythmia

Variability Assessments

Clinical studies have demonstrated that heart rate variability, QTc variability and T-wave morphological variability are risk indicators for cardiovascular and sudden death. These three forms of variability can be measured on five-minute recordings, yielding a prognostic profile that **cannot be reliably derived from a traditional 10-second recording.**

Other Assessments

The five-minute recording is used to detect late potentials using signal averaging. This further contributes to the risk profile. One of the most useful analyses is the Diagnostic Statements listing, illustrated in **Figure 5** and **Figure 6**. This listing can be used to detect evanescent diagnostic criteria and to assess their importance. **Figure 6** illustrates a case in which the computer algorithm (Glasgow) diagnosed definite inferior infarction on one 10-second ECG and possible inferior infarction on 23 others. No infarct was diagnosed on the remaining six 10-second ECGs. Varying inferior Q-wave presence and amplitude is a well-known ECG problem, and is well illustrated in this case. The limb lead recordings during some periods showed clear diagnostic Q waves in leads 2, 3 and aVF, while during other periods the Q-wave was preceded by a small, variable R-wave (**Figure 7**).

In this case, the Summary ECG showed diagnostic Q-waves; the averaging process had virtually eliminated the preceding R-wave. **The Summary ECG approach may be helpful in determining the “truth” when diagnostic criteria vacillate.** This particular patient had a past history of myocardial infarction.

Triplicate ECGs

The recording (or extraction) of triplicate or higher multiples of traditional 10-second ECGs at discrete time points has become a commonplace method to reduce the influence of biological and methodological variability of the ECG in pharmaceutical trials. Analyzed properly, the five-minute ECG **eliminates the need for recording triplicates.** It is the equivalent of 10 times as many individual recording periods and it reduces the influence of outlier data more substantially than just three traditional recordings.

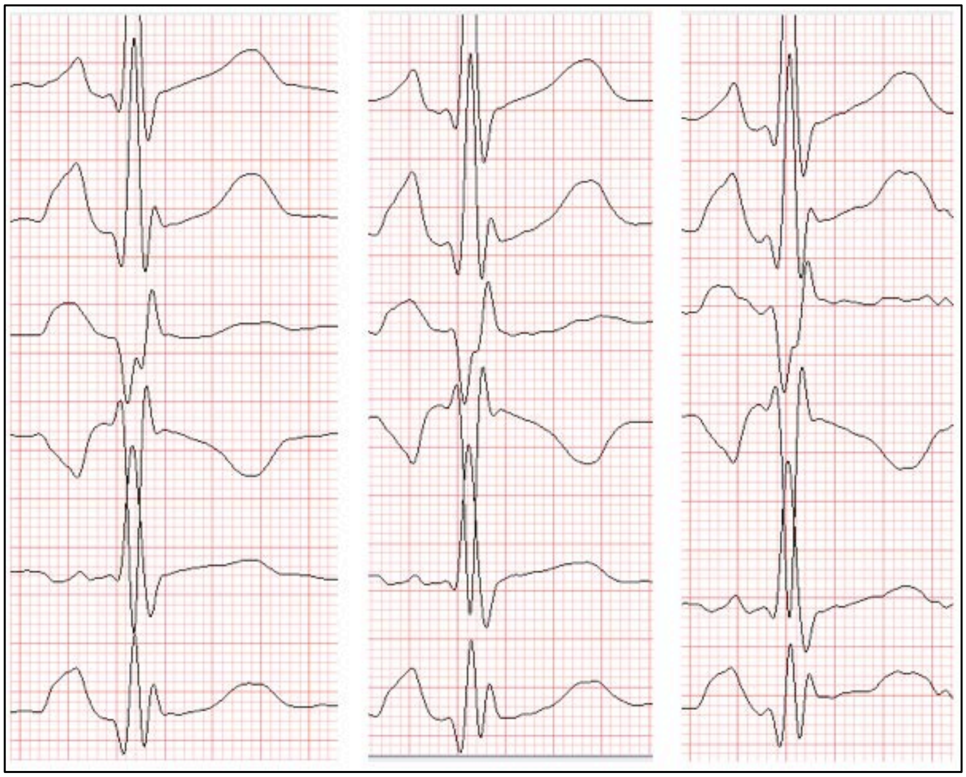


Figure 7: Varying inferior Q-wave criteria in the patient above. Leads 1, 2, 3, aVL, and aVF are displayed from top to bottom in the three panels. The lefthand panel show clear Q-waves in leads 2, 3 and aVF. The middle and right panels show preceding R-waves of varying amplitude.

DISADVANTAGES OF A FIVE-MINUTE RECORDING

The *Summary ECG* has some disadvantages. By definition, it is based upon normal beats. Thus, it does not itself provide any arrhythmia information. In fact, it may obscure the presence of an arrhythmia that would have been detected by the single 10-second ECG. The Summary ECG shown in **Figure 8** provides an example. The ECG appears to show normal sinus rhythm. However, lead 2 and several other leads contained an odd artifact preceding each P-wave (see red arrows in **Figure 8**).

A selected 10-second ECG extracted using AMPS Antares software shows the arrhythmia responsible for this artifact (**Figure 9**) because it was present throughout the five-minute recording (**Figure 10**). Comparison of that tracing to the Summary ECG also serves to illustrate the noise-reduction associated with the Summary ECG method (see, especially, the inferior leads).

Other telltale artifacts of this sort seen in this case have been observed in other recordings that included very frequent arrhythmias. This example makes clear the need to check the diagnosis list for arrhythmias not seen on the Summary ECG, and, in some cases, to review the full recording.

Other diagnoses that might have been made with isolated 10-second ECGs theoretically could be masked on the Summary ECG. For example, varying normal and abnormal PR duration or intraventricular conduction delay could be averaged to a normal value on the Summary ECG. Of course, in these cases, the traditional 10-second ECG would be equally misleading, showing either a normal or abnormal value rather than an average value.

Variability Assessment

The variability analyses described above have obvious potential for deriving richer clinical information from the ECG. However, in the cases of QTc and T-wave morphology variability, there is not sufficient clinical experience to establish normal ranges for normal individuals or patients with various disease states. As time passes and sufficient data is collected, these measures will become more valuable.

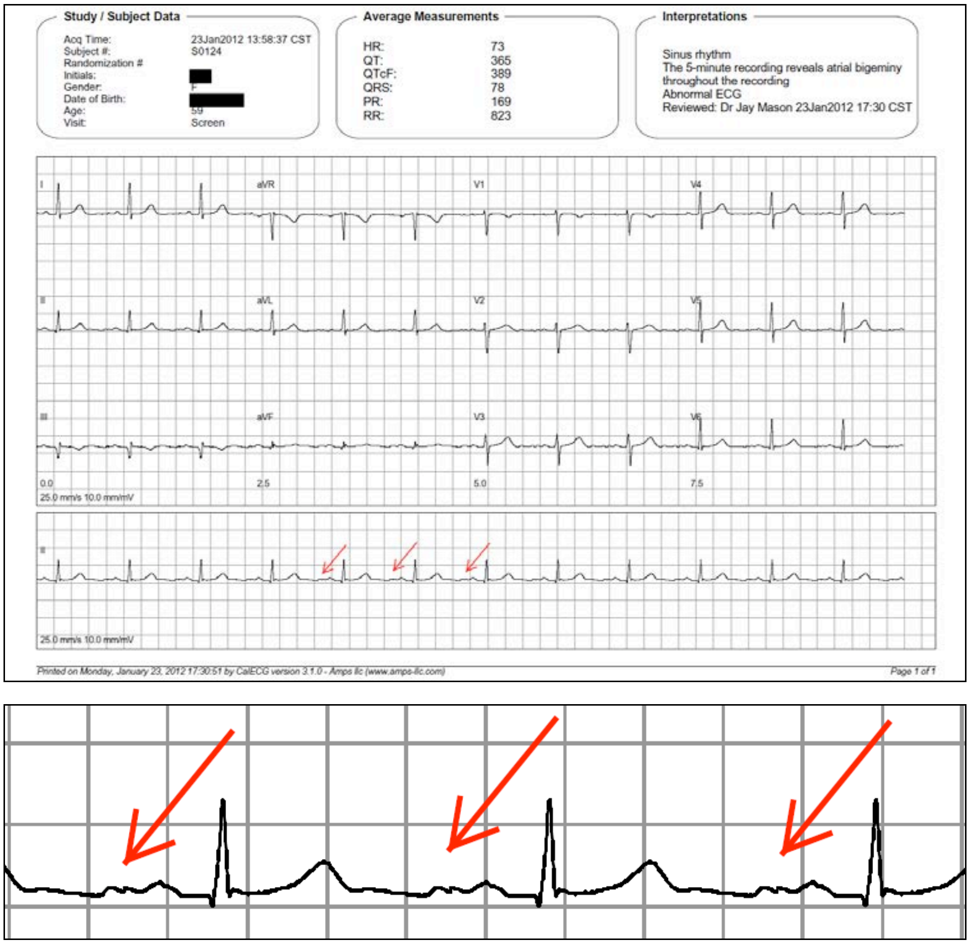


Figure 8: Summary ECG in a patient with persistent atrial bigeminy. The lower panel is an enlarged detail wave form from lead 2 in the upper panel. Red arrows point to telltale artifact.

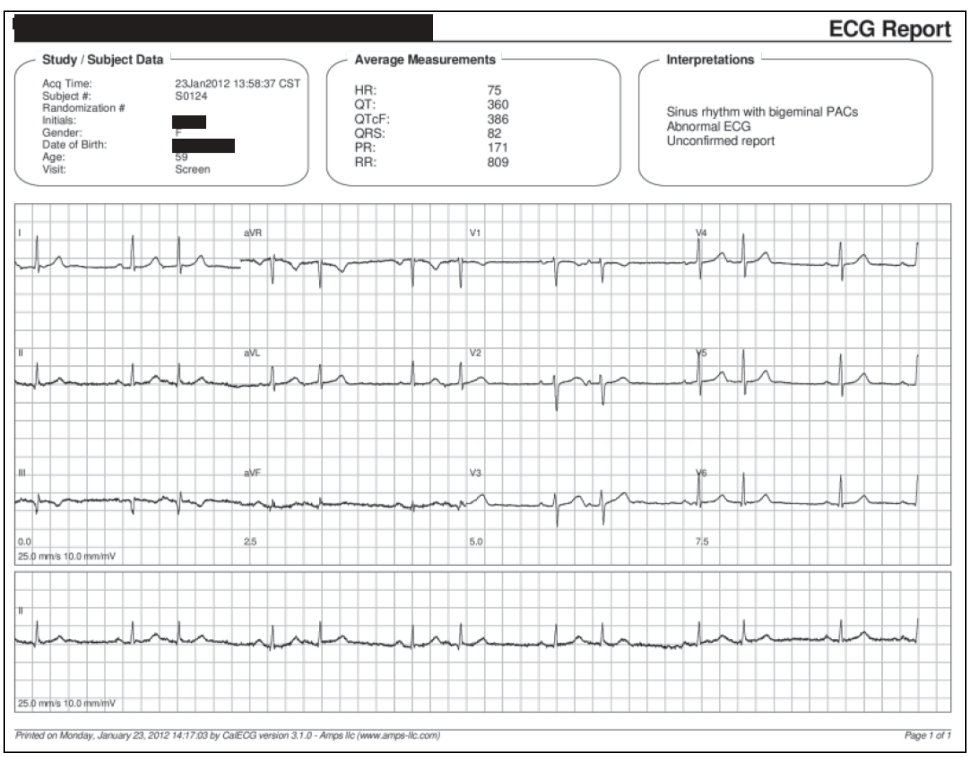
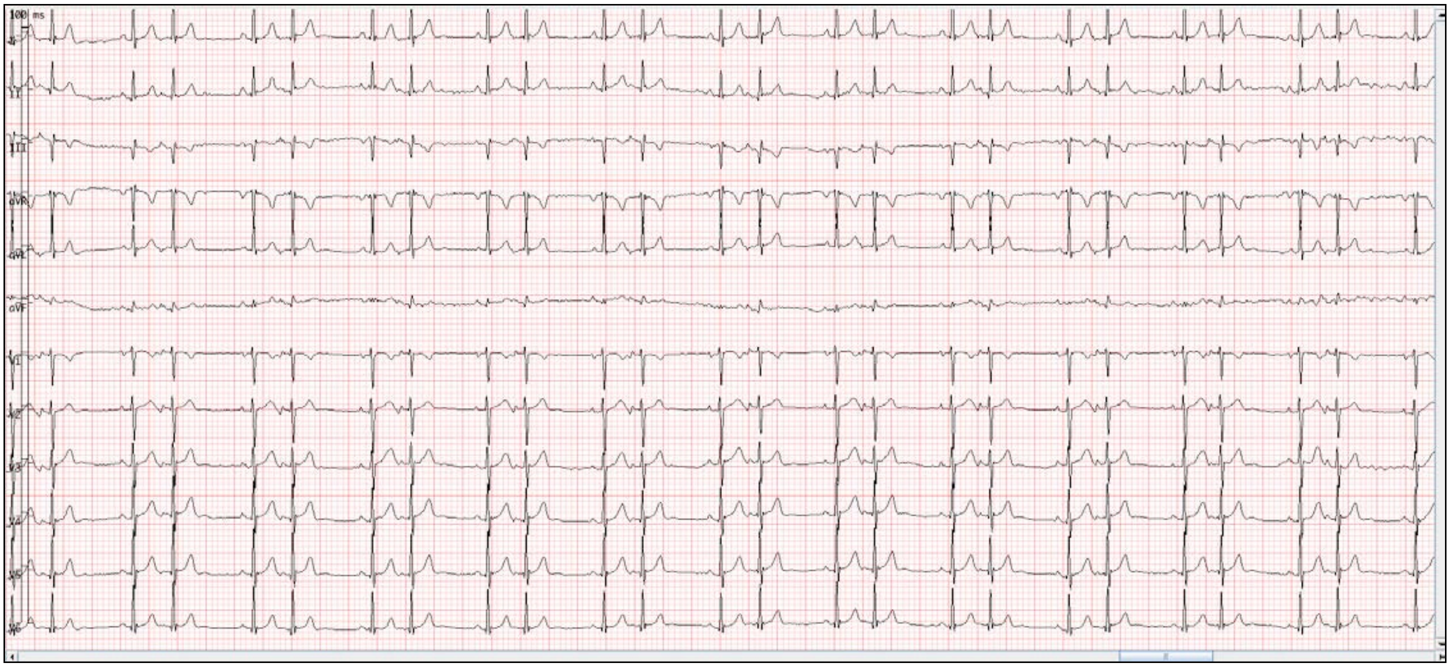


Figure 9: Antares-selected 10-second ECG in patient above.

Figure 10: 20-second segment from the five-minute recording of the patient above.



Other Disadvantages

The five-minute ECG cannot be performed in many circumstances. Infants and young children cannot stay still for a full recording. Long recordings are also impossible in some critically ill patients or those undergoing procedures that cannot be interrupted for five minutes.

The five-minute ECG may take longer to perform than a standard ECG, though the method used reduces or eliminates many procedural steps in the acquisition and storage of the ECG, making the total work effort less than that associated with traditional recordings.

The five-minute recording unequivocally takes longer to review and interpret. However, some of this extra burden can be reduced by using clever workflow, prompting and other software aids for the reader.

The five-minute ECG requires more electronic storage space than a standard ECG. On the other hand, the full file is small enough that its transfer over the Internet is essentially instantaneous using the typical bandwidths found in medical practice and research.

Finally, the *Summary ECG* is not equivalent to the traditional 10-second ECG. While it makes sense to use existing normative ranges in interpreting the Summary ECG, eventually new normal values need to be established for the Summary ECG. The bright side of this requirement is that, when established, the new normative range is certain to be diagnostically more reliable because it will be based upon more robust data.

CONCLUSION

Cardiac rhythm and other physiological manifestations captured by the ECG are too variable to be properly portrayed by the traditional 10-second sample. Just as one would never use a single blood pressure measurement to determine if antihypertensive therapy is needed, one should not rely on a 10-second ECG recording to make critical clinical or research decisions.

As was outlined above, the five-minute ECG has the benefits of:

- A summary ECG with a more accurate analysis;
- A better assessment of arrhythmias;
- No need for triplicate recordings;
- The ability to assess other parameters such as variability.

It is clear that the technology and knowledge to use electrocardiography more rationally than it is used today is now available and should be explored further. The five-minute ECG should be a part of that exploration.

ABOUT THE AUTHOR

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Jay W. Mason, M.D., is a world-renowned cardiac drug safety expert with 35+ years of experience in cardiac care and research. He graduated from Princeton and obtained his MD degree from the University of Pennsylvania. He also trained in Medicine and Cardiovascular Diseases at Stanford University where he was a member of the faculty from 1975-83. He was Chief of Cardiology at the University of Utah from 1983-99 (where he still serves as a faculty member) and served as Chairman of the Department of Medicine at the University of Kentucky from 1999-2003. Dr. Mason's clinical, teaching and research emphasis is in cardiac arrhythmias and electrophysiology. He has authored over 400 publications and has served on the National Research Review Committees for the NIH and the American Heart Association. He has also served on several editorial boards, including the *American Journal of Cardiology, Circulation, Annals of Internal Medicine, American Journal of Medicine,* and the *Journal of the American College of Cardiology*.