The University of Glasgow (Uni-G) ECG Analysis Program

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Abstract

The University of Glasgow 12/15 lead ECG analysis program has been in continuous development for over 20 years. It has been adapted to meet the needs of different users and keep abreast of changes in terminology as well as new morphological features described in the literature. It is applicable to neonates as well as adults and takes account of racial variation in wave amplitudes. It has a capability for comparing serially recorded ECGs using one of two different approaches. The many varying features of the software have led to the introduction of the descriptor Uni-G (unique) ECG analysis program.

1. Introduction

Methods for the analysis of electrocardiograms using automated techniques were first investigated in the University of Glasgow in the late 1960's. The earliest of publications introduced methods for processing waveforms recorded in groups of three leads simultaneously, whether they were from X, Y, Z orthogonal leads or carefully selected groups of three leads from the 12-lead ECG, e.g. I, aVF, V1 (1,2). At the end of the 1970's, a decision was made to move to develop a 12-lead ECG analysis program where all leads were recorded simultaneously. A digital electrocardiograph was designed and built locally (3) and with this, ECGs could be collected in digital form to permit further development of software for analysis and interpretation. Indeed, this instrument was capable of acquiring 11 leads simultaneously so that a complete 12-lead plus an orthogonal 3-lead ECG could be obtained simultaneously.

Throughout the 1980's, there was a major effort to collect databases from apparently healthy individuals of all ages from birth onwards and various publications presenting these data have appeared previously (4, 5). Full details will be published in a new edition of Comprehensive Electrocardiology (6). Diagnostic criteria evolved therefrom in a variety of ways and a comprehensive 12-lead ECG analysis program was introduced for worldwide interpretation of ECGs (7).

2. Methods

2.1. Signal processing

The University of Glasgow (Uni-G) ECG interpretation program is based on an analysis of 8 or 11 simultaneously recorded leads acquired at 500 samples per second. The first stage in analysis is to apply a 50 Hz or 60 Hz notch filter to remove AC interference if this has not already been done by the electrocardiograph itself.

Thereafter, methods for detection of excessive artefact are used and if leads are found to have an unacceptable quality of recording, the five seconds in which this is found, i.e. the first or second half of the recording is set to be a continuous value. It was found that it could be beneficial to retain five seconds of a lead given that noise very often occurs in short, one or two second bursts.

The next stage in the analytical process is QRS detection and typing. Effectively, a function based on a combination of available leads is formed from which putative QRS complexes are determined. Thereafter, wave typing is undertaken using an iterative process whereby the first complex in Lead I is compared with the second to look for any differences. The technique is extended to include all complexes in this lead and then repeated for four other leads, as often it is only one or two leads which clearly show an aberrantly conducted complex.

A complex selection procedure then decides which class of beat will be selected for averaging and subsequent interpretation. At this stage, cognisance has to be taken of whether or not any beats are paced and although the software itself has routines for detecting and removing pacemaker stimuli, this is best achieved by front end processing with signals sampled at a much higher rate, e.g. 8,000 samples per second within the electrocardiograph firmware itself. If this is done, a list of pacemaker spike locations is forwarded to the Uni-G program and the spike artifacts are removed from the data.

The program has optional approaches to computing the average QRS cycle including a simple mean, a weighted mean and a median beat. In different commercial versions, manufacturers may utilise their own proprietary

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software for beat averaging if desired.

Different approaches to finding fiducial points have been tried, including a simple form of threshold crossing to a more complex template matching technique. Ultimately, a combination of these approaches has been adopted where, for example, QRS onset was found to perform best with respect to a noisy test set using a threshold technique. On the other hand, T-end performed best using a template matching method. All QRST amplitudes are referred to QRS onset as are P wave measurements, which represents a departure from an early approach where a straight line was fitted between P onset and P termination.

Individual QRS and T fiducial points are derived for all leads and a method of selecting the earliest QRS onset for example is utilised in order to determine a global QRS onset. A similar approach is adopted for QRS termination and the difference between the two global measurements is taken as the overall QRS duration. It was found optimum to utilise a common P onset and P termination in view of the unreliability of P wave detection in many ECGs.

The wave measurement section of the program meets all the requirements of the relevant IEC test procedures as shown in Table 1.

Table 1. This table shows the mean and standard deviation of the difference between the measurements made by the Glasgow program and by 5 referees in the 100 ECGs in the CSE measurement set. The values in [] are the IEC acceptable differences and standard deviations for global durations and intervals for biological ECGS. It can be seen that the program results are well within the recommended tolerances.

Difference	Mean	Standard Deviation
P Duration	1.348 [10]	8.501 [15]
QRS Duration	1.609 [10]	6.354 [10]
PR Interval	1.043 [10]	6.747 [10]
QT Interval	0.602 [25]	9.669 [30]

2.2. Rhythm analysis

The approach to rhythm analysis remains as before (8) in that three leads are used. These are II, V1 and a third lead selected from limb leads, usually the one with the largest P wave amplitude in the case of sinus rhythm. The basic rhythm strategy is to determine a dominant rhythm such as sinus rhythm or atrial fibrillation and thereafter determine any supplementary abnormalities such as first degree AV block or ventricular extrasystoles.

A significant amount of work was done on the use of neural networks to attempt to improve the accuracy of determining atrial fibrillation (9) but ultimately it was found that deterministic methods were equally acceptable. Differentiation of atrial fibrillation with rapid ventricular response from sinus tachycardia with frequent supra VES still remains a difficult problem for automated techniques.

Relatively recently, newer methods for enhancement of reporting atrial flutter were reported by the group (10). While logic for detection of saw tooth waves has always been present, the more recent logic adopted a threshold crossing technique combined with regularity of intervals between peaks resulting in an improvement in the sensitivity of reporting atrial flutter from 27% to 79%, with a specificity exceeding 98% in both cases.

2.3. Diagnostic interpretation

The diagnostic component of the software is capable of using age, sex, race, clinical classification and drug therapy within its logic. Experience has shown, however, that many staff, particularly nursing staff, will simply not take the time to input the appropriate measures to the software, even the age and sex of a patient which it is known are fundamental to accurate interpretation.

The basic approach to interpretation is through the use of rule based criteria, but relatively recently this approach has been enhanced in several ways. First of all, smoothing techniques were introduced (11) to try to minimise repeat variation in interpretations by avoiding the use of strict thresholds between abnormal and normal. In short, instead of a step function separating normal from abnormal an exponential or even a linear function between the normal and abnormal threshold value can be used as illustrated. This is usually associated with a scoring technique whereby it can be seen that a small change in voltage for example results in a small change in score. In the case of multiple parameters, more complex combination rules apply as discussed elsewhere (12).

Neural networks have also been introduced for detection of abnormal Q waves. However, it was found in practice that these perform best in combination with deterministic criteria (13).

Electrocardiography has not stood still in recent years and new terminology such as ST elevation myocardial infarction (STEMI) has been introduced. The software acknowledges the newer diagnoses and a significant amount of work has been done to adapt the output appropriately (14). Another example of newer terminology is that of the Brugada pattern of which account has to be taken (Figure 1).

The software makes extensive use of age and sex of

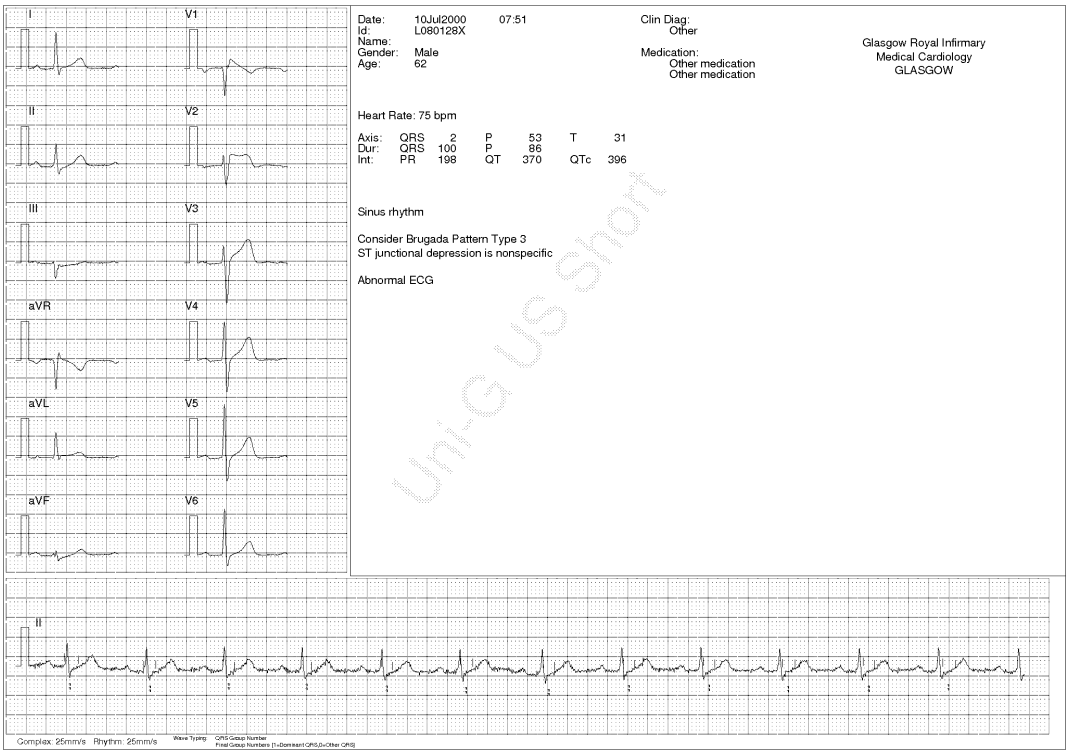

Figure 1: Example showing Brugada pattern

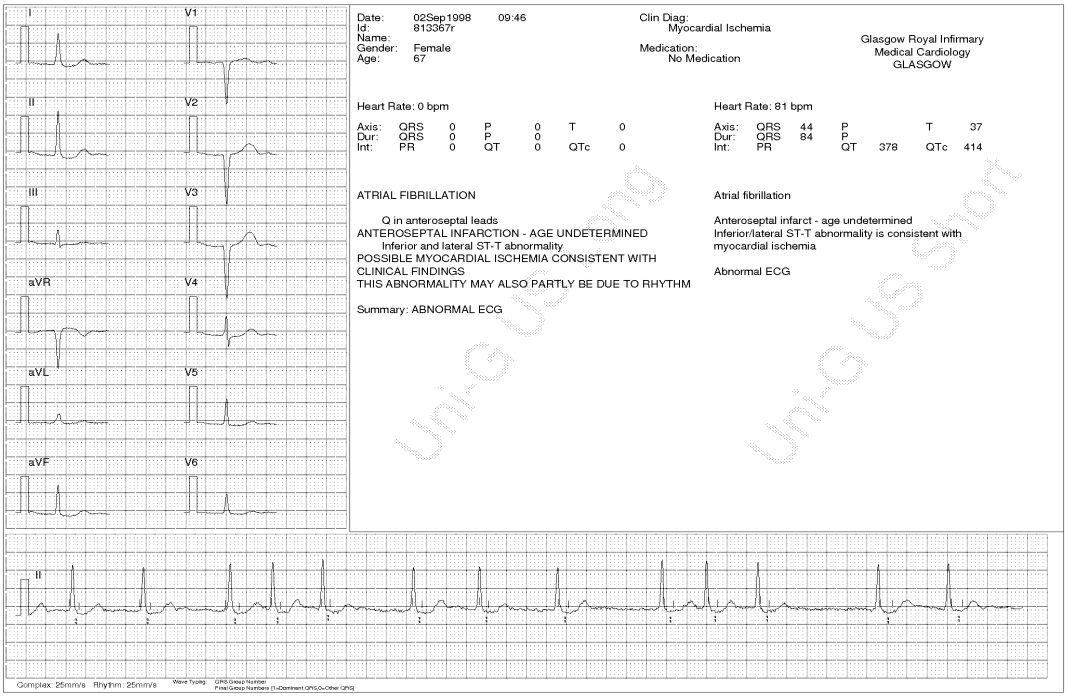

Figure 2: Example showing two styles of report presentation for illustrative purposes only. The brief format is on the right while the long format with reasons is shown on the left.

patients in reaching an interpretation. Continuous limits of normality have been introduced particularly for children and younger males while different equations for normal limits of amplitudes are used for males and females especially in the younger adult age ranges. To a certain extent, the race of a patient is acknowledged through lower limits of normal voltage for Chinese individuals, for example.

Finally, the software contains methods for comparison of serial tracings. Two approaches are utilised the first of which involves integrating criteria within the main logic leading to statements such as "serial changes of myocardial infarction" (15). A newer approach has been to add on separate logic for serial comparison, which then functions as a secondary program that is run following the main diagnostic logic. In this case, there are advantages of having almost all serial comparison logic in the same section of code although it is perhaps an approach more favoured in North America than elsewhere. This, therefore, highlights the question of user choice which also applies to the style of output presentation. Two different styles are offered, one whereby explanatory reasons are printed along with a diagnostic statement and the other where a much more brief diagnostic comment is produced. The different styles can be compared in Figure 2 where a research style output is produced to illustrate the different approaches.

Finally, it should be remarked that the program has a capability of handling 15 leads and the user is at liberty to select for example V3R, V4R and V7 even although the diagnostic logic at present does not incorporate criteria from these leads. If the additional leads happen to be X, Y, Z leads computed from the 12-lead ECG using an inverse Dower transformation for example (16), then additional vectorcardiographic measurements can be made and vectorcardiographic loops output.

3. Discussion and conclusions

The Uni-G program has continued to evolve over a long period of time and could still be said to be under development, given the changing fashions in medicine and the underlying fact that the 12-lead ECG still remains the most commonly used diagnostic test in clinical medicine despite the availability of much more complex procedures. The ECG still provides unique information which, in many ways is complementary to the newer techniques but is obtained in a much more simple and rapid fashion as demanded in many clinical situations.

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