70-00821-02 B

Burdick® 8300 and 8500 Electrocardiograph

ECG Interpretation Criteria Physician's Guide
Brief Format Statements

CARDIAC science™

ECG Interpretation Criteria
Physician's Guide

Brief Format Statements

Burdick
8300/8500

70-00821-02 B

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AT THE HEART OF SAVING LIVES®

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1 Introduction

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Note: Computer assisted interpretation is a valuable tool when used properly. No automated analysis system is completely reliable, however, and interpretations should be reviewed by a qualified physician before treatment, or non-treatment, of any patient.

Welcome to the latest edition of the Physician's Guide that accompanies the ECG interpretive program. The aim of this Physician's Guide is to provide a list of the criteria currently used for ECG interpretation in Burdick/Quinton electrocardiographs. The ECG interpretation criteria are part of a program for ECG analysis that has evolved over many years and which was developed by the University of Glasgow Division of Cardiovascular and Medical Sciences, Section of Cardiology based in the Royal Infirmary, Glasgow, Scotland. Burdick/Quinton has worked closely with the team at the University of Glasgow to adapt and update this program for use by its customers. While some criteria are traditional, others have been developed through research studies and the need to quantify what, for many ECG abnormalities, has essentially been a subjective analysis of waveforms. Feedback from users has also helped to shape the latest release of the software.

For the first time, this Physician's Guide provides an extensive outline of the approach to wave measurement and interpretation used by the University of Glasgow program. This follows from a requirement of the IEC 60601-2-51 specifications relating to "essential performance of recording and analyzing single channel and multichannel electrocardiographs". As in the past, the Physician's Guide also provides a detailed outline of criteria used by the program and provides data on program performance.

Historical considerations

Methods for the automated analysis of ECGs have been under continuous development in Glasgow since the late 1960's. A separate document reviewing the more historical aspects from early work on semi automated analysis of one cardiac cycle from three orthogonal leads and from the 12 lead ECG recorded in four groups of quasi orthogonal leads through to fully automated analysis of 10s of the 12 lead ECG with all leads recorded simultaneously is available [1]. That document also refers to various studies in which the software has been involved through the years.

The remainder of this chapter deals with the methodology used in the currently available version of our software, which has become known as the University of Glasgow program specially for Burdick/Quinton devices.

ECG wave recognition

The methodology for ECG waveform measurement is described in general terms in an earlier publication from the Glasgow Laboratory [2]. 10 seconds of ECG data is input to the software for analysis and all leads require to have been acquired simultaneously.

Preprocessing

Initially, a 50Hz or 60Hz notch filter is applied to remove any AC interference, if such a filter has not already been applied within the acquiring device. The first stage of the analysis is to compute any missing limb leads from the minimum of two leads that need to be provided. The ECG data is then filtered to minimize the effects of noise. The next step in the analysis is to calculate a form of spatial velocity combining the first difference of each lead. From this function, the approximate locations of all the QRS complexes are derived. Allowance has to be made for pacemaker stimuli, which are ideally detected by the front end equipment and passed to the program in the form of a list of "spike" locations.

Given the QRS locations, it is then possible to check the quality of the recording for noise and baseline drift. If the drift is excessive, it is removed by using a cubic spline technique to obtain, for each lead affected, the baseline trend, which is then subtracted from the original data. If the noise is excessive, it is possible to remove a whole lead from the analysis or alternatively, 5 seconds of all leads are removed either from the first or second half of the recording.

QRS typing

Thereafter, the various QRS complexes are typed according to their morphology. An iterative process is used. Effectively, the first complex in lead I is compared with the second using first differences of each cycle. The comparison takes the form of moving one beat over the other and when the difference is minimal, optimal alignment is present. This alignment point is used for averaging as discussed below. If the difference between beats is less than a threshold value, they are deemed to belong to the same class. The procedure is repeated with the third beat being compared with the second and so on. If a new morphology is detected, i.e. if the threshold is exceeded, a new class is established. The procedure continues with five leads being used in the typing process.

Selection of required QRS class

If more than one class of beat is present, then a decision has to be made as to which morphology will be used for the averaging procedure, i.e. the cycle to be interpreted has to be selected. A complex logic is used for this purpose. It has to allow for a single normally conducted beat in the midst of demand pacemaker beats for example. It also needs to take account of the QRS durations of different beat classes, RR intervals to exclude extrasystoles, and to a limited extent, the number of beats in each morphological class. The net effect is to choose one class of beats, of a similar morphology, that are regarded as being conducted in the normal sequence through the ventricles.

Averaging

All beats in the selected class are averaged so that 12 such beats, one from each lead, are then available. The "average" beat can be computed in several ways. Common to this are the alignment points detected when wave typing was undertaken. They are used as reference points in the averaging process. The average beat can be a straight average of all corresponding aligned points, it can be a median calculated from the same points or it can be a weighted average - the so called modal beat introduced into the program in 1977 [3]. In this version, the program uses a special representative beat formation developed by Cardiac Science Corporation.

Wave measurement

From the 12 average beats, a single combined function is formed and a provisional overall QRS onset and termination is determined by thresholding techniques. The provisional onset and termination are then used as starting points for a search for QRS onset and termination within each individual lead. Basically the approach conforms to the recommendations of the CSE working party [4] (of which one of the Glasgow team was a member), which were published in 1985.

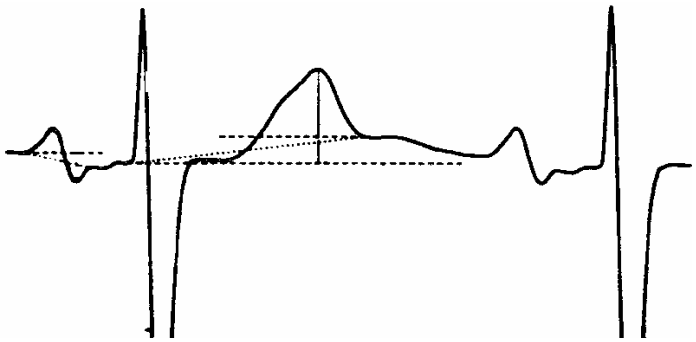

Figure 1-1: **Varying choice of baselines - reproduced from [4].**

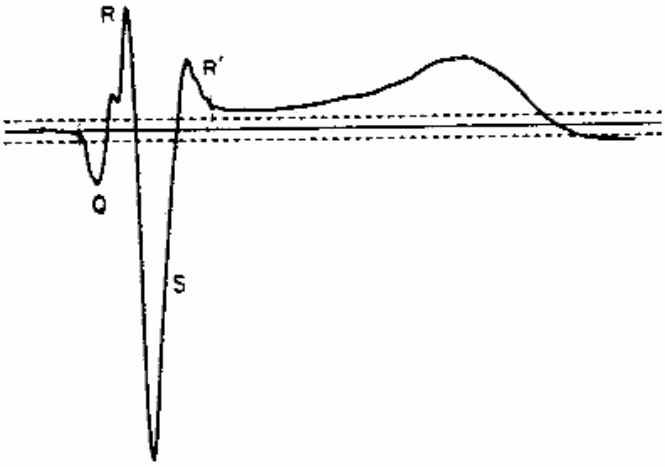

Figure 1-2: **Baseline at the level of QRS onset as used by the Glasgow program - reproduced from [4].**

In each individual lead, the QRS onset is taken as the baseline and hence Q, R, S, R' waves are measured with respect to the QRS onset as shown in the accompanying figures from the CSE paper (see Figure 1-1 through Figure 1-4). Isoelectric segments at the beginning of a QRS complex, i.e. a flat segment between the provisional overall onset and the onset of an individual lead are excluded from the first component (Q or R) of the QRS complex as recommended by the CSE group. Similar considerations apply at the end of the QRS complex (see Figure 1-3). A sorting algorithm is then applied to all 12 onsets to determine the global QRS onset as follows. The earliest onset is excluded and the next onset that also lies within 20 ms of the next again is then selected as the overall onset. This ensures that any true outliers are excluded. The reverse process is used to find the overall QRS termination.

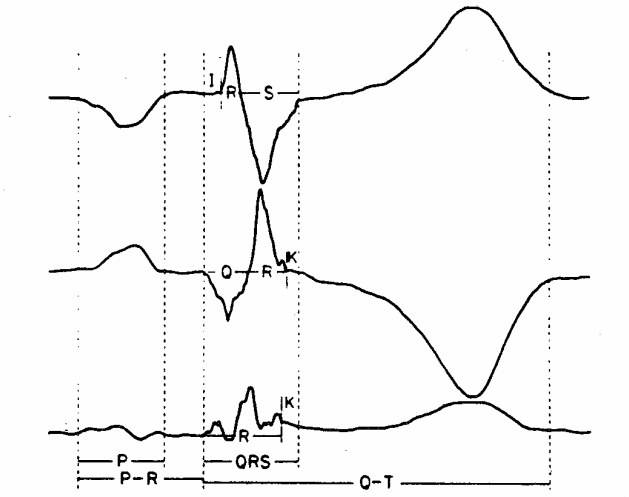

Figure 1-3: **Illustration of isoelectric segments I and K - reproduced from [4].**

QRS components

Within the QRS complex, the amplitude and duration of the various Q, R, S, R' waves are then measured. In keeping with the CSE recommendations [4], the minimum wave acceptable has to have a duration >8 ms and an amplitude >20 µV. With respect to global QRS duration, the Glasgow program measures QRS duration from the global QRS onset to the global QRS termination. This means that an isoelectric segment within one particular QRS complex by definition will lead to a shorter QRS duration for that lead compared to the global QRS duration.

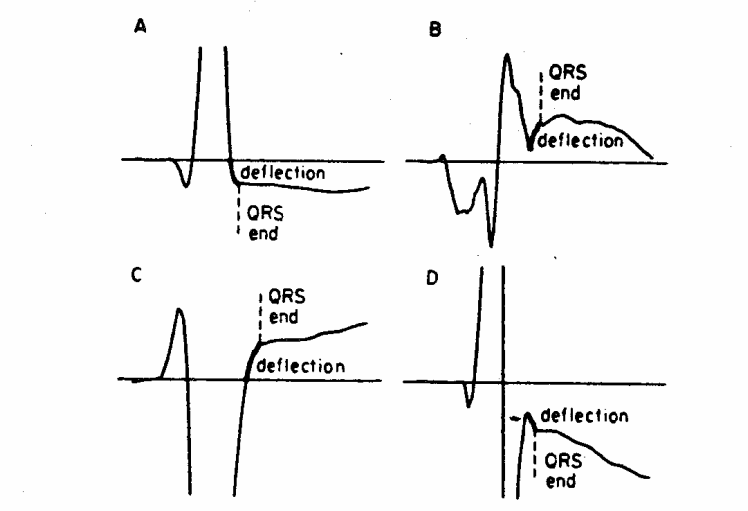

Figure 1-4: **Definitions for QRS end / ST junction - reproduced from [4].**

ST segment

The ST segment has several measurements made. Figure 1-4 shows the J point as used in the diagnosis of ST elevation myocardial infarction. However, measurements are also made at equal intervals throughout the ST segment, e.g. 1/8 ST-T, 2/8 ST-T, etc.

P and T waves

A search for the P wave is made in the interval preceding the QRS complex. A P wave may not always be found in certain arrhythmias. P onset and termination are found using a method involving second differences but the same P onset and termination is used over all 12 leads in view of the difficulty in detecting low amplitude P waves in many leads. P wave amplitude is determined with respect to the same baseline as for Q, R, S amplitudes, namely the QRS onset. This was found to be more reliable than fitting a straight line between P onset and P termination even in cases where the P wave was superimposed on the T wave in the case of a tachycardia.

T end is determined for each lead using a template method. The global T end is derived in a similar fashion to the global QRS offset. The other components of the ECG waveform, namely the ST and T wave amplitudes, are also measured with respect to QRS onset. Thus, the ST junction and the various ST amplitude measurements, such as ST 60 and ST 80 as well as the positive and negative components of the T wave, are all measured with respect to the QRS onset. The reason for this is that it is the most straightforward approach to measurement.

Interval measurements

With respect to intervals, the global QT interval is measured from the global QRS onset to the global T end. On the other hand, because the P onset is taken as being simultaneous in all 12 leads, the global PR interval measurement is from the P onset to the global QRS onset.

Normal limits

The above methods were used to determine the normal limits of QRS waveforms from an adult database of over 1500 normals, published in Comprehensive Electrocardiology, 1989[5] and a pediatric database derived from 1750 neonates, infants and children, published in part in 1989[6] and 1998[7] and which will be published in much more detail in the next edition of Comprehensive Electrocardiology. These normal limits are essentially an integral part of the diagnostic software.

Diagnostic approach

Rhythm analysis

The QRS onsets and terminations used in wave typing are transferred to the rhythm program together with the measurement matrix of the 12-lead ECG. These data are used in determining the rhythm interpretation [8].

Three leads only are used for rhythm analysis. These are selected on the basis of the P-wave amplitudes determined by the wave-measurement program acting on the average beat. Leads II and V1 are always chosen and a third lead is selected from I, III, aVF and aVR, depending on the P-wave amplitude. In general, the above applies in the presence of an expected sinus rhythm. If flutter has been detected in Lead II, then Leads III and V1 are the other two leads which would automatically be used.

If no significant P wave was found in the average beat, such as would occur very often in atrial fibrillation or other arrhythmias, such as complete heart block, the leads selected for analysis are II and V1, with two different P-wave morphologies being adopted for the latter.

Because P waves have a different morphology in different leads, the template used for P wave searching varies depending on the lead under consideration. For example, if lead aVF has been selected and the P-wave amplitude is predominantly negative, then the template used for P-wave detection would be that of an inverted P-wave having first a negative, followed by a positive gradient as exemplified in the first difference of the data. P-wave searching is carried out from the end of an RR interval, i.e., from just before QRS onset in a reverse direction to the approximate end of the preceding T wave. If in any particular RR-interval P-waves are found to be absent, it is possible to alter critical values in the template and repeat the search. If a single P wave is found, then it would be retained. If multiple P waves are found, then they would be ignored being regarded as almost in the noise of the ECG.

A variety of special subroutines has been developed through the years for different purposes. For example, in complete AV dissociation the P waves would be regularly spaced, but with no relationship whatsoever to the QRS complex. For this reason, a subroutine would check the regularity of any P wave detected and make allowance for the fact that some may have been missed on account of being submerged in the QRS or T wave. A PP-regularity index can then be calculated and a decision made on whether regular P waves, which are dissociated from the QRS complex, have occurred.

The data from the average beats are also used to assess the likelihood of sinus rhythm being present where, of course, a definite P wave would be found in the average cycle in the vast majority of cases of sinus rhythm.

The overall strategy of the approach is to detect sinus rhythm as early as possible in the logic by looking for the presence of regular rhythm with a single P wave in each RR interval and an essentially high value of PR regularity. Of course, the latter would be

found in abnormalities such as 2-1 AV block and the presence of multiple P waves must be eliminated prior to the diagnosis of sinus rhythm. However, if pure sinus rhythm has been found, then an early exit from the rhythm analysis can be made. In all other cases, a more detailed analysis of rhythm commences.

Abnormalities of the PR interval are assessed both on the basis of the median cycle and the PR interval as measured by the rhythm program. In cases of an extremely prolonged PR interval as in First Degree AV Block, only the rhythm program would accurately detect the lengthened PR interval.

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 Glasgow 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.

Morphological interpretation

The diagnostic component of the software is capable of using age, gender, 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 gender of a patient which it is known are fundamental to accurate interpretation.

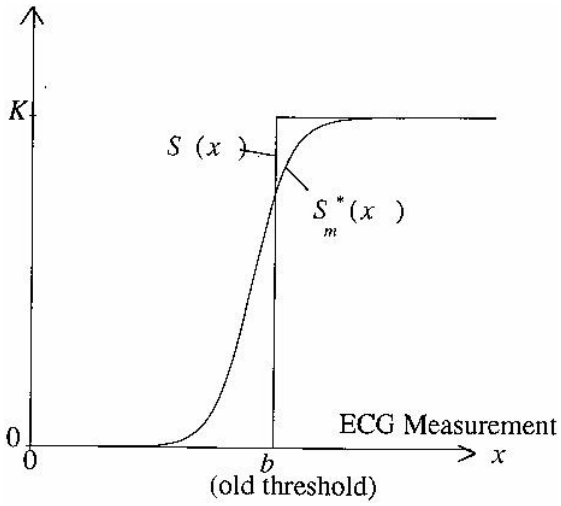

Figure 1-5: **Replacement of a step function threshold with an exponential function. With the step function, K points are scored when the ECG measurement exceeds the threshold 'b'. With the exponential function, the score varies continuously.**

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 minimize 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 (see Figure 1.5). This is 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 terminology 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 has to be taken into account.

The software makes extensive use of the age and gender of patients in reaching an interpretation. Continuous limits of normality have been introduced particularly for children and younger males while different equations for normal limits 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 Asian individuals, for example.

Intended use of program

Diagnostic application

The Glasgow Program is intended to provide an interpretation of the resting 12 lead ECG in all situations, whether this be in a hospital or primary care setting. It is capable of diagnosing all commonly recognized ECG abnormalities such as myocardial infarction (MI), including acute MI, ventricular hypertrophy, abnormal ST-T changes and common abnormalities of rhythm. Conduction defects and other abnormalities such as prolonged QT interval are also reported. The software is not designed for interpretation of exercise electrocardiograms. The software has been widely used in clinical trials (e.g. the West of Scotland Coronary Prevention Study [15]) and hence has had wide exposure to recording of electrocardiograms in all commonly required situations.

Intended population

The Glasgow Program is intended for use in adults and children of any age from birth upwards. The Program makes significant use of the patient's age and gender and indeed operates at the level of days in the case of neonates [6],[16]. It is believed to be the only program that is based on normal limits derived using the algorithm itself with this applying to criteria for subjects of all ages, including neonates. Indeed, it is known that other developers utilize the Glasgow normal limits.

Intended location

The Glasgow Program is intended to be used in the hospital or in a general physicians office, or in out of hospital locations such as an ambulance. It is able to accept details of the patient's name, age, gender, and automatically invokes the appropriate criteria and routines such as special logic for acute cardiac ischemia where necessary. There cannot be any difference in ECG appearances of acute myocardial infarction depending on the location of ECG recording - it is only the prevalence of the abnormality that will vary.

Diagnostic accuracy

The program is designed to be as accurate as possible with the emphasis being, if anything, towards a high specificity given that the criteria are based on the normal limits already described. Nonetheless, the program has high sensitivity for detecting all cardiac abnormalities as is evidenced by the results presented in the following section. In short, the program aims for the highest sensitivity at a high specificity although there is always a trade off between one and the other.

Program specific information

Introduction

This version of the software includes criteria for ST elevation myocardial infarction or STEMI. Of course, criteria for Q wave infarction remain. Several new statements dealing with ST-T changes in the presence of ventricular hypertrophy have been added in this version. As for the previous release, all statements have been redesigned so that reason statements are no longer necessary to supplement the diagnosis. In addition, most of the diagnostic statements have been further shortened compared to earlier versions. It is believed this will make the output more user friendly; the use of upper and lower case characters should also assist in the review process.

Pediatric aspects

The Physician's Guide also contains pediatric criteria. Such criteria are automatically invoked when age is less than 16 to 18 years depending on the particular criterion under consideration. A unique feature of the Glasgow program is that continuous equations of upper limits of normal measurements are used. In general, such measurements will increase linearly from birth to adolescence. An example is QRS duration, which has an upper limit of 80 milliseconds at birth increasing to approximately 115 milliseconds at 18 years of age. Some measurements may reach their adult value at less than 18 years of age.

The pediatric criteria can make use of lead V4R when it is available. While this enhances the accuracy of ECG interpretation in this age group, the program will still function when the conventional 12-lead recording positions are used in children (although the use of V4R to the exclusion of V3 is preferred). Full details of how to select the appropriate lead configuration for input to the electrocardiograph can be found in the relevant electrocardiograph operating instructions chapter.

Age related information

Similarly, the mechanism for specifying the age of a patient can also be found in the operating instructions. In the case of neonates and infants, the age will be calculated in days if the date of birth is input (for ages up to 364 days). If an age is input in years only, the criteria will be less efficiently used because the continuous equations employed allow the advantage of utilizing the age in days or months (age in months can be used for ages over 1 year). For example, for a patient who is 1 year and 11 months old, an age of 23 months should be entered as opposed to an age of 1 year. Clearly, there will then be significant differences in the upper limit of normal using continuous equations based on the age in days or months compared to using an age in years.

A similar concept has been previously introduced for dealing with the upper limit of normal voltages for the diagnosis of ventricular hypertrophy in adults and children. Instead of discrete limits being used for particular deciles of age, continuous age dependent limits are now used.

Smoothing

Finally, with respect to the new methodology, a major effort has been made to minimize the effect of diagnostic thresholds in ECG criteria. There has to be a border between normal and abnormal but the newer approach tries to smooth such boundaries by, for example, awarding only a small increment to a score if a measurement exceeds a threshold by only a small amount.

Presentation of criteria

A principal aim in preparing this manual was that the criteria should, wherever possible, be presented in a relatively straightforward form. At the same time, it was intended that the text should convey the unique flavor of the approach used for ECG analysis within Burdick/Quinton brand devices. For this reason, a compromise has been adopted where, for some criteria, a generalized statement has been made rather than a precise quantification of numerical data being listed. Even so, the list of criteria is somewhat detailed but it should be appreciated that computers do require a certain amount of precision! Detailed criteria for arrhythmias are not listed although the various statements that can be produced by the program are presented.

The layout of the criteria should be self-explanatory. In general terms, the wave amplitudes have positive or negative amplitudes in the conventional sense, e.g. the S wave is regarded as having a negative amplitude. Similarly, a criterion which requires that T- < -0.1 mV means that the negative T wave amplitude should be in excess of -0.1 millivolts, e.g. this would be true if T- = -0.2 mV (see Figure 1-6 on page 1-16). Occasionally, the absolute value of a negative wave or ratio is denoted by | |.

Use of clinical data

A unique feature of the program is the ability to make use of age, gender, drug therapy and clinical classification of the patient. The full list of clinical classifications that may influence the interpretation is as follows:

- Normal
- Myocardial Infarction
- Myocardial Ischemia
- Hypertension
- Congenital Heart Disease
- Rheumatic (Valvular) Heart Disease
- Pericarditis
- Respiratory Disease
- Implanted Pacemaker
- Endocrine Disease
- Pulmonary Embolism
- Post-operative Cardiac Surgery
- Cardiomyopathy
- Other
- Unknown

The list of drug therapies accepted is as follows:

- Digitalis
- Diuretic
- Beta Blocker
- Quinidine
- Procainamide
- Amiodarone
- Disopyramide
- Lidocaine
- Other antiarrhythmics
- Psychotropic drugs
- Steroids
- Calcium Blockers
- NitratesAce Inhibitors
- Alpha Blockers

- No medication
- Unknown medication
- Other medication

The manner in which the clinical information is used will be apparent from a study of the criteria presented in this manual. It should be stressed that this approach is optional and in the event that the user does not wish to use clinical data, an interpretation will still be produced. It is, however, our strong belief that the ECG should be interpreted on the basis of a knowledge of the patient's clinical condition, as well as age and gender, and for that reason it is recommended that the age, gender and clinical information are input to the electrocardiograph to enhance the quality of the diagnostic statement. Full details of the operation and programming of the electrocardiograph can be found in the relevant manual.

Waveform descriptors

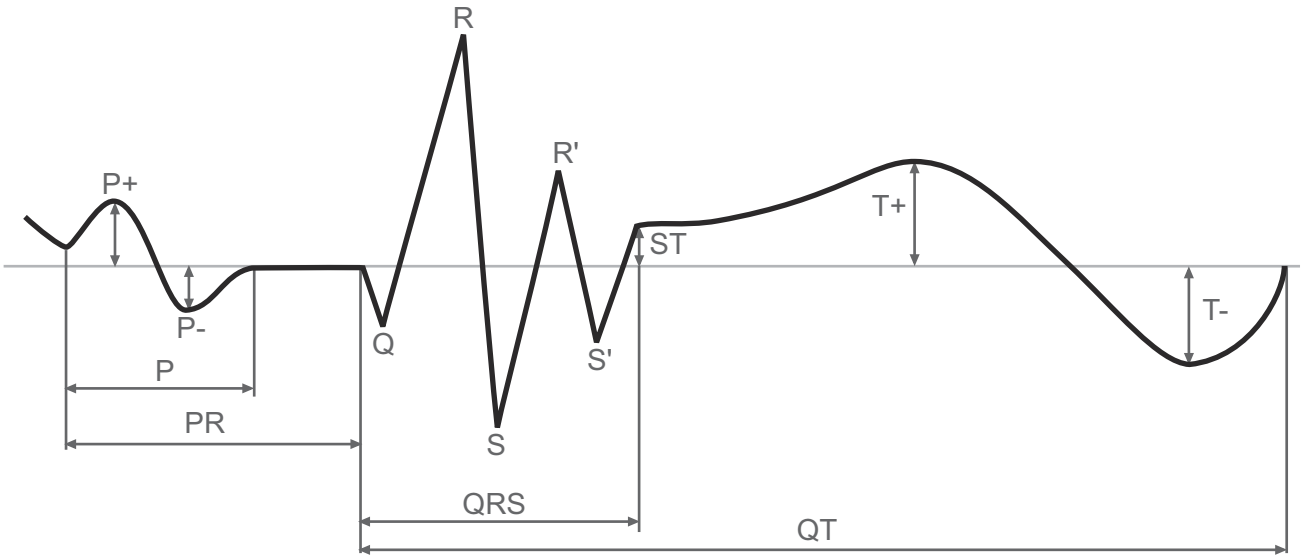

Figure 1-6: **Measurement reference**

Overall P onset, P offset, QRS onset, QRS offset and T termination are determined from all 12 leads. Individual lead wave amplitudes are then obtained.

P+ and P- are measured with respect to a straight line fitted between overall P onset and offset.

Q, R, S, R', S', T+ and T- amplitudes are measured with respect to a horizontal line through the lead QRS onset. Durations are measured between relevant points.

Areas are measured in units of millivolts x milliseconds (mV x ms). Units of measure are not specified when an area measurement appears in the criteria.

Isoelectric components between the overall QRS onset and an individual lead onset are not included in a Q or R duration (see Figure 1-3 on page 1-5).

Throughout the Physician's Guide, the criteria may make reference to P or T wave morphologies where the morphology may be described as a number between -2 and +2. These morphologies refer to the wave shapes as shown in Figure 1-7 below:

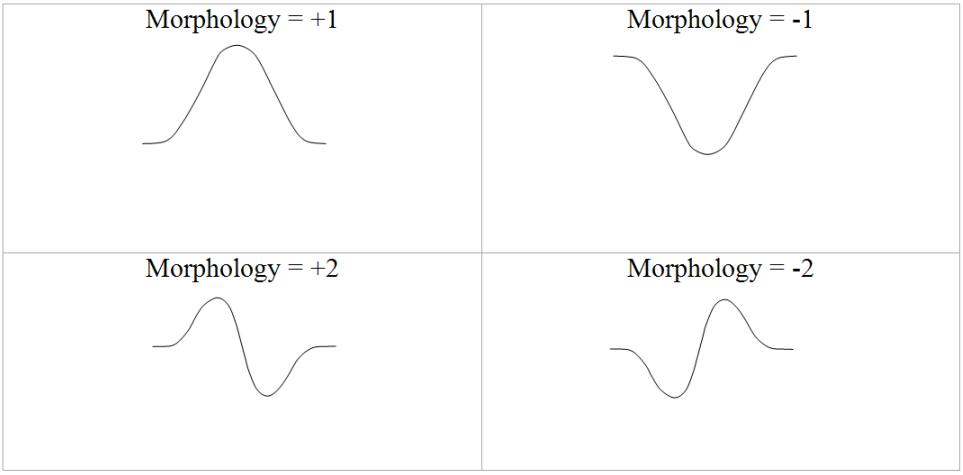

Figure 1-7: **Morphology descriptors**

2 Preliminary Comments

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- RESTRICTED ANALYSIS 2-5
- MISCELLANEOUS PRELIMINARY STATEMENTS 2-5
- PEDIATRIC ECG ANALYSIS 2-5

This introductory section of the diagnostic software checks the validity of the leads. The criteria apply to ECGs recorded from patients of all ages.

STATEMENTS

1. Possible faulty Vn - omitted from analysis

For leads V2 - V5:

	(a)		i.	peak-peak QRS in any one of V2 to V5 < 0.35 mV and < 1/3 peak-peak QRS of the leads on either side
		or	ii.	if the peak to peak QRS in any one of V2 to V5 <0.5 mV and < 1/5 peak-peak QRS of the leads on either side
and	(b)			T+ < 0.10 mV with T- > -0.10 mV in that lead

2. Possible faulty V6 - omitted from analysis

	(a)	peak-peak QRS in V6 < 0.3 mV, and < 1/3 peak-peak QRS in V5
or	(b)	peak-peak QRS in V6 < 0.5 mV, and < 1/6 peak-peak QRS in V5
or	(c)	if P+ = 0 in V6 with QRS area in V6 < -200 and QRS area in V5 > 200

3. Possible sequence error: Vn, Vn+1 omitted

For leads V2 - V5:

	(a)		i.	the QRS area in Vn is negative, and the QRS area in the leads on either side is positive
		or	ii	the QRS area in Vn < 25% of the area for Vn-1 and Vn+1, and all areas have the same sign
and	(b)			|QRS area| > 500 in Vn-1, Vn, and Vn+1

4. Lead(s) unsuitable for analysis:

If any of the leads is not present, the above statement is printed with the appropriate lead identified.

5. --- Possible measurement error ---

The maximum absolute value of the P+ or P- wave in any lead exceeds 1.0 mV.

LEAD REVERSAL/DEXTROCARDIA

This section of the program aims to detect the faulty application of the limb leads and to differentiate it from dextrocardia. The criteria are age dependent and allowance has to be made for the fact that Lead V3 may not be available in children.

CRITERIA

A.			the P wave flag is set
B.			100° < P axis ≤180° or -180° < P axis < -100°
C.			90° < QRS axis ≤180°, or -180° < QRS axis < -90° and the QRS area in Lead I is negative
D.			in V6, the peak to peak QRS > 0.5 mV, with the QRS area > 0 and P+ > P-
E.		i.	$0 \leq R(n+1) \leq R(n)$ for n = V3, V4, V5 or $R \leq 0.1$ mV for all of V3, V4, V5, V6
	and	ii.	100 > QRS area (n+1) > QRS area(n) for n = V3, V4, V5, and in V6, peak to peak QRS < 0.8 mV, with R < 0.1 mV, and QRS axis > 60°
F.		i.	in I, $\|Q\| > R \geq R'$, or ($\|S\| > R'$, with Q = 0 and $R' \neq 0$)
	and	ii.	in V6, S > 0.25 mV or $\|R/S\| \geq 2$
	and	iii.	ST polarities are opposite in I and V6 as are T wave amplitudes
G.			R and R' amplitude < 0.135 mV
H.			$\|S\|$ and $\|S'\|$ amplitude < 0.05 mV
J.			$\|Q\|$ < 0.06 mV
K.			$\|$QRS area in lead I + QRS area in lead III$\|$ < 0.1 mV
L.			T+ + $\|T-\|$ < 0.05 mV
M.			$\|$QRS area in lead II - QRS area in lead I$\|$ < 0.1 mV

STATEMENTS

1. --- Suspect arm lead reversal - only aVF, V1-V6 analyzed ---

	(a)		A and B and C and (D or F) true and age > 180 days
or	(b)		C and F true and (not A) and age > 180 days
or	(c)		A and B and $\{ \Sigma T_I \times \Sigma T_{V6} < 0 \}$ and age ≤ 180 days where $\Sigma T_I = T_I+ - \lvert T_I- \rvert$ and T+ is the amplitude of the positive component of the T wave and T- is the amplitude of the negative component of the T wave

2. --- Suggests dextrocardia ---

	(a)			1 is not true
and	(b)		i.	A and B and E are true
		or	ii.	(not A) and C and E are true

3. --- Suspect limb lead reversal - only V1-V6 analyzed ---

	(a)	G, H, J, and L are true for lead II
and	(b)	K is true
or		
	(c)	G, H, J, and L are true for lead III
and	(d)	M is true

RESTRICTED ANALYSIS

If it is not meaningful to interpret the QRS-T morphology for whatever reason, one of the following statements will be printed.

1. **Pacemaker rhythm - no further analysis**
2. **--- No further analysis due to lack of dominant QRS ---**
3. **--- Similar QRS in V leads ---**

MISCELLANEOUS PRELIMINARY STATEMENTS

The following statements can be printed in the event of faulty input of clinical data. The analysis continues with default values chosen.

1. **--- Invalid clinical data entry ---**

   (a) clinical classifications are normal + any other

   or (b) clinical classifications are unknown + any other

2. **--- Invalid medication entry ---**

   (a) drugs are unknown + any other

PEDIATRIC ECG ANALYSIS

If an ECG from a subject under 17 years of age is analyzed, the following statement will be printed.

1. **--- Pediatric criteria used ---**

3 Heart Rate

Contents

- *** EXTREME TACHYCARDIA *** 3-2
- TACHYCARDIA 3-2
- *** EXTREME BRADYCARDIA *** 3-3
- BRADYCARDIA 3-3

The limits for tachycardia and bradycardia are clearly age related in the neonatal and pediatric age range. In the program, a continuous limit of normality is used for certain age ranges such as from birth to 28 days (see example below). These data were obtained from a study of over 1,750 healthy neonates, infants and children.[1]

Note: The final limits of 100 and 60 are user programmable.

Example: For a neonate of 14 days of age, the tachycardia limit is 172/min and the bradycardia limit is 96/min.

*** EXTREME TACHYCARDIA ***

This statement will be output if the heart rate exceeds the limit for age shown in the table below:

Age Range	Rate in beats/min.
Birth to 28 days	213 increasing to 230
29 days to180 days	230
181 days to 17 years	230 decreasing to 150
≥18 years	150

TACHYCARDIA

Age Range	Rate in beats/min.
Birth to 28 days	163 increasing to 180
29 days to 180 days	180
181 days to 17 years	180 decreasing to adult default limit
≥18 years	adult default limit

Note: The adult default limit for tachycardia, (default 100 BPM), is user programmable in the range of 81 to 129 BPM.

Note: Tachycardia limits are age dependent for neonatal and pediatric patients. For neonatal and pediatric patients, the ECG device interpretive software disregards the Tachycardia Limit setting and uses predefined limits (between 100 and 180, depending upon age).

1. Heart rate is calculated from the average RR interval.

*** EXTREME BRADYCARDIA ***

This statement will be output if the heart rate is below the limit for age shown in the table below:

Age Range	Rate in beats/min.
Birth to 28 days	73 increasing to 90
29 days to 365 days	90
1 year (366 days) to 6 years (2191 days	90 decreasing to 45
6 years (2191 days) to 12.5 years (4600 days)	45 decreasing to 40
≥12.5 years (4601 days and older)	40

BRADYCARDIA

Age Range	Rate in beats/min.
Birth to 28 days	88 increasing to 105
29 days to 365 days	105
1 year (366 days to 6 years (2191 days)	105 decreasing to 60
6 years (2191 days) to 12.5 years (4600 days)	60 decreasing to adult default limit
≥12.5 years (4601 days and older)	adult default limit

Note: The adult default limit for bradycardia, (default 60 BPM), is user programmable in the range of 41 to 60 BPM..

Note: Bradycardia limits are age dependent for neonatal and pediatric patients. For neonatal and pediatric patients, the ECG device interpretive software disregards the Bradycardia Limit setting and uses predefined limits (between 60 and 105, depending upon age).

4 Intervals

Contents

- PR INTERVAL 4-2
- QT INTERVAL 4-3

The normal limit of PR interval is age dependent and the appropriate continuous equation is utilized in the software. To control specificity, it was decided to maintain the upper limit of normal for adolescents and adults at 200 ms although there is evidence that it may be slightly less than this value particularly in the younger of these age ranges.

Since QT interval is essentially heart rate related, an age dependent equation has not been utilized. However, if the heart rate exceeds 125 per minute, no statement on corrected QT interval is printed. This approach also applies if the QRS duration is in excess of 120 ms.

PR INTERVAL

Omit this section if:

(a) the P wave flag (from rhythm analysis) is not set
or (b) the rhythm is not **Sinus rhythm**
or (c) WPW pattern is present

STATEMENTS

1. Short PR interval

(a) the PR interval is less than the lower limit for age as specified in the table:

Age range (years)	Limit (ms)
0 - 15	[75 + 0.006*age(days)]
16 and over	110

2. with 1st degree A-V block

(a) the PR interval ≥ the age dependent limit as specified in the following table.

Age	Limit (ms)
≤ 18 years	[163 + 0.0087*age(days)]
> 18 years	220

3. with borderline 1st degree A-V block

(a) 2(a) is not true
and (b) the PR interval ≥ the age dependent limit as specified in the following table

Age	Limit (ms)
≤ 18 years	[143 + 0.0087*age(days)]
> 18 years	200

Note: Statements 2 and 3 are determined by the rhythm analysis.

QT INTERVAL

If the QRS duration ≥ 120 ms, or if the heart rate exceeds 125/minute, omit this section. The criteria in this section use the corrected QT interval denoted QTc. This is calculated from one of the following equations:

Hodges[a] (default)	$QTc = QT + 1.75 \times (\text{heart rate} - 60)$
Bazett[b, c]	$QTc = QT\ (RR)^{-1/2}$
Fridericia[d]	$QTc = QT\ (RR)^{-1/3}$
Framingham[e]	$QTc = QT - 154\ (RR - 1)$
where	RR = mean RR interval, in seconds

a. Hodges M et al. Bazett's QT correction reviewed - Evidence that a linear QT correction for heart is better. *J Am Coll Cardiol*. 1983, 1(2): 694

b. Bazett HC. An analysis of the time relations of electrocardiograms. *Heart*, 1920;7: 353-370

c. Taran LM et al. the duration of the electrical systole (Q-T) in acute rheumatic carditis in children. *Am Heart J*. 1947; 33:14-26

d. Fridericia LS. Die Systolendauer im Elektrokardiogramm bei normaln Menschen und bei Herzkranken. *Acta Med Scan*. 1920;53:469-486

e. Sagie A et al. An improved method for adjusting the QT interval for heart rate (the Framingham Heart Study). *Am J Cardiol*. 1992;79:797-801

Note: QTc equation selection may be an optional feature on some electrocardiographs. Hodges is the default selection[1].

STATEMENTS

1. Prolonged QT interval

	(a)			male and QTc ≥ 460 ms
or	(b)			female and
			i.	age ≥ 50 years and QTc ≥ 470 ms
		or	ii.	age < 50 years and (rate < 110 and QTc ≥ 460 ms or rate ≥ 100 and QTc ≥ 470 ms)

2. Short QT interval

	(a)	QTc ≤ 350 ms

1. Luo, S et al. Comparison of commonly used QT correction formulae: the effect of heart rate on the QTc of normal ECGs. J *Electrocardiol*. 2004;37(suppl):81-90

5 Conduction Defects

Contents

- INTRAVENTRICULAR CONDUCTION DEFECTS 5-2
- WOLFF-PARKINSON-WHITE PATTERN 5-5

The duration criteria for conduction defects are age dependent. As indicated in the Introduction, it is possible to utilize an equation to calculate the upper limit of QRS duration from birth to adolescence and a similar concept can be applied to determine the normal limits of the duration of Q, R, S waves individually. In order not to complicate the criteria listing, certain duration values are listed as a constant value plus an age dependent variable denoted by LIM1 or LIM2 or LIM3. The following table lists the values of these three variables at birth and in adolescence. Adult criteria are obtained by using the higher of the values while pediatric criteria are derived from an age dependent value intermediate to the two limits.

	Birth	Adolescence
LIM1	0	32 ms
LIM2	29	35 ms
LIM3	40	45 ms

As an example, Criterion 1a indicates that the R or R' duration in Lead I has to exceed 68 ms at birth or 100 ms in adulthood for the criterion to be met, while at age 10, the critical duration would be approximately 85 ms.

Although constant values are specified in the criteria, the discrete thresholds between normal and abnormal have been replaced by continuous functions. These functions were introduced to improve the repeatability of the program. Algebraic rules have been used to combine criteria.

INTRAVENTRICULAR CONDUCTION DEFECTS

STATEMENTS

1. Extensive IVCD

(a) in Lead I, R or R' > LIM1 + 68
and (b) in Lead I, T+ < 0.1 mV and T- < -0.1 mV
and (c) in V1, R or R' > LIM3
and (d) the QRS spatial velocity at 4/8 or 5/8 < 40 mV/sec
and (e) in V1, both Q and S have duration ≤ LIM1 + 68 or amplitude ≥ -1 mV

2. Left bundle branch block

A.

(a) the QRS spatial velocities at any two of 4/8, 5/8 and 6/8 < 100 mV/sec
and (b) i. in Lead I, V5 or V6: R > LIM1 + 68, with Q > -0.02 mV
or ii. in Lead I, V5 or V6: R' > LIM1 + 68, with S > -0.02 mV
and (c) in V1, either Q or S ≥ LIM1 + 58 with amplitude < -1 mV
and (d) (R+R') duration summed over I, V5 and V6 > 3*(LIM1 + 58)
and (e) R amplitude/R duration < 20 in I and (V5 or V6) with |R/S| > 4
and (f) QRS duration ≥ LIM1 + 88 in any two leads
and (g) in V2, sum of R+R' < 0.3 mV

or B.

None of the previous statements is true and from the following criteria either:

(a and b and c and d and f) is true
or (b and d and e and f) is true

(a) QRS duration > LIM1 + 88 in any two leads
(b) i. in Lead I, V5 or V6: R > LIM1 + 68, with Q > -0.02 mV
or ii. in Lead I, V5 or V6: R' > LIM1 + 68, with S > -0.02 mV
(c) i. in Lead I, S ≤ LIM2, or S ≥ -0.15 mV, or |R/S| ≥ 4
and ii. in Lead I, S' ≤ LIM2, or S' ≥ -0.15 mV, or |R'/S'| ≥ 4
(d) in V1 or V2, either Q or S > LIM1 + 68, with corresponding amplitude < -1.0 mV
(e) the QRS spatial velocity at 4/8 and 5/8 < 100 mV/sec
(f) (R+R') duration summed over I, V5 and V6 > 3*(LIM1 + 58)

3. Incomplete LBBB

	(a)		i.	in V5 or V6, R > LIM1 + 38, with Q > -0.02 mV
		or	ii.	in V5 or V6, R' > LIM1 + 38, with S > -0.02 mV
and	(b)		i.	in V5 or V6, 100 ms < QRS < 130 ms
		and	ii.	in V1 or V2, 100 ms < QRS < 130 ms
and	(c)			the QRS spatial velocities at 4/8 and 5/8 < 100 mV/sec
and	(d)		i.	in I, S ≤ LIM2, or S ≥ -0.15 mV or |R/S| > 4
		and	ii.	in I, S' ≤ LIM2, or S' ≥ -0.15 mV or |R'/S'| > 4

4. Right bundle branch block

A.

	(a)			QRS duration in V5 or V6 > LIM1 + 68, and QRS duration in V1 or V2 > LIM1 + 68
and	(b)		i.	in I, V5 or V6, S > LIM2, and S < -0.14 mV, and|R/S| < 4
		or	ii.	in I, V5 or V6, S' > LIM2, and S' < -0.14 mV, and |R'/S'|< 4
and	(c)			in V1 or V2, R or R' > 45 ms
and	(d)		i.	the QRS spatial velocity at 4/8 or 5/8 < 40 mV/sec
		or	ii.	the QRS spatial velocity at 6/8 < 40 mV/sec with the QRS spatial velocity at 6/8 less than at 7/8
and	(e)			in V1, T- < -0.1 mV
and	(f)			QRS axis is not between -30° and -120° or R > |S| in II
and	(g)		i.	QRS axis is not between 100° and 135° and age > 6 months
		or	ii.	R and R' in Lead II < 0.8 mV
		or	iii.	R and R' in Lead III < 1 mV
		or	iv.	RVH is present
and	(h)			QRS duration > LIM1 + 78 in any two leads
and	(i)			WPW type A is not present

or B.

			i.	(a and b and c) or (d and e)
		and	ii.	(f) is true
	(a)		i.	QRS > LIM1 + 78 in any two leads
		and	ii.	QRS duration > LIM1 + 83 or RVH is not present
	(b)			in Lead V1 or V2, R > LIM3 with S = 0, or R' > LIM3
	(c)		i.	in Lead I, S, S' and R all have 0 amplitude, and Q is not 0
		or	ii	in Lead I, V5 or V6, S > LIM2, and S < -0.14 mV or |R/S| < 4
		or	iii.	in Lead I, V5 or V6, S' > LIM2, and S' < -0.14 mV or |R'/S'| 4
	(d)			R or R' in Lead V1 > LIM1 + 88
	(e)			delta confidence value in Lead V1 is 0
	(f)		i.	overall QRS axis is not between -30° and -120°
		and	ii.	R and R' in lead II < 0.8 mV
		or	iii.	R and R' in lead III < 1 mV
		or	iv.	RVH is present

5. RBBB with left anterior fascicular block

Test (a) below replaces tests (f), (g), (h) in RBBB part A
or Test (a) below replaces tests (f), in RBBB part B

i. -120° < overall QRS axis < -30° and R > |S| in II
and ii. inferior myocardial infarction is not present

6. RBBB with RAD - possible left posterior fascicular block

Test (a) below replaces (f), (g), (h) in RBBB part A
or Test (a) below replaces (f) in RBBB part B

i. 100° ≤ overall QRS axis ≤ 135° and age > 6 months
and ii. R or R' in Lead II ≥ 0.8 mV
and iii. R or R' in Lead III ≥ 1 mV
and iv. RVH is not present

7. IV conduction defect

None of the previous statements is true and from the following criteria either:

(a) is true
or (b and c) is true.
(a) QRS duration ≥ LIM1 + 88 in any two leads
(b) in V1 or V2, Q or S > LIM1 + 68
(c) i. in lead I or V5, R > LIM1 + 68, and Q > -0.02 mV
or ii. in lead I or V5, R' > LIM1 + 68, and S > -0.02 mV

8. Incomplete RBBB

(a) i. in V1 or V2, R' ≥ 0.2 mV and, in the same lead, R' -ST amplitude > 0.05 mV and S' > 0.2 mV, and R' > R
and ii. QRS duration < LIM1 + 88 ms
and (b) i. there is no atrial fibrillation or flutter
or ii. there is atrial fibrillation or flutter and R' amplitude > 3*max (P+, P-)

9. rSr′(V1) - probable normal variant

(a) i. in V1 or V2, 0.15 mV < R' < 0.2 mV and, in the same lead, R' -ST amplitude > 0.05 mV and S' > 0.2 mV and R' > R
and ii. QRS duration < LIM1 + 88 ms
and (b) i. there is no atrial fibrillation or flutter
or ii. there is atrial fibrillation or flutter and R' amplitude > 3*max (P+, P-)

WOLFF-PARKINSON-WHITE PATTERN

In order to keep the criteria as sensitive as possible, the age dependence of the criteria in this section is extremely limited. The variable LIM1 is defined on page 5-1.

CRITERIA

A.			there is a 70% confidence of Delta Waves in any two of V1 - V6
B.		i.	PR + QRS < 300 ms
	and	ii.	PR < 120 ms
C.		i.	PR < 170 ms
	and	ii.	PR + QRS < 320 ms
D.			there is a 90% confidence of Delta Waves in any two of Leads I, II, III, aVR, aVL, aVF
E.			there is a 70% confidence of a Delta Wave in V1, and R in V1 > 0.5 mV, and S in V1 > -0.5 mV
F.			there is a 70% confidence of a Delta Wave in V4 or V5 or V6, and R in V1 ≤ 0.5 mV and R in V5 ≥ 0.5 mV and Q in V4 and V5 > -0.05 mV
G.			there is 90% confidence of a Delta Wave in V1 and R in V1 > 0.5 mV, and S in V1 > -0.5 mV
H.			there is 90% confidence of a Delta Wave in V4 or V5 or V6 and R in V1 ≤ 0.5 mV and R in V5 ≥ 0.5 mV and Q in V4 and V5 > -0.05 mV
J.			R wave in V5 or V6 > 3 mV and the R in V1 ≤ 0.5 mV and there is a 30% confidence of a Delta Wave in I, V5 or V6
K.			QRS > LIM1 + 88 ms
L.			R in V1 > 0.5 mV and there is a 30% confidence of a Delta Wave in V1
M.			in V1, the QRS area > 0
N.			in V5, the QRS area > 0 and M is not true

STATEMENTS

1. WPW pattern

	(a)			A is true
and	(b)		i.	(B and E) or (C and G) are true
		or	ii.	(B and F) or (C and H) are true

2. Possible WPW pattern

1.

	(a)			1 is false
and	(b)		i.	(B and L) or (C and E) are true
		or	ii.	(B and J) or (C and F) are true
and	(c)			K is false

or 2.

	(a)			1 and 2.1 are false
and	(b)			A or D is true
and	(c)			C is true
and	(d)		i.	M is true
		or	ii.	N is true

6 Hypertrophy

Contents

- LEFT VENTRICULAR HYPERTROPHY 6-2
- RIGHT VENTRICULAR HYPERTROPHY 6-5
- BIVENTRICULAR HYPERTROPHY 6-8

LEFT VENTRICULAR HYPERTROPHY

If WPW or LBBB has been detected, this section is omitted.

The criteria for LVH are in the form of points awarded for each test with the points being totaled to give a final score. In a fashion similar to the use of a continuous equation for a normal limit of duration, it is feasible to use such an equation for upper limits of normal voltage of Q, R and S amplitudes. Such equations are used for diagnosing LVH in children in which case the continuous equations are on occasions split into two with one equation being from birth to one month of age and the other being from one month until adolescence. It is also worth noting that equations are dependent on race and at the present time, separate equations are available for Caucasian and Asian adults.

For convenience, a short table of significant limits is presented below. Limits for children are intermediate to those for birth and 17 years.

For clarity, the criteria describe discrete thresholds and integer scores. However, as in other parts of the program, the discrete thresholds have been replaced by smooth continuous functions which return continuous scores. These are combined, where required, with other criteria using algebraic rules and the resulting overall score is used to determine the diagnostic statement that is output.

CRITERIA

A. amplitude (use only the maximum score from criteria i - v). Each part scores 2 points. In addition, Part i scores 1 extra point for each 0.3 mV over the limit. Parts ii, iii , and v score 1 extra point for every 0.5 mV over the limit for patients aged 17 and over. Also, 1 point is deducted from i - v if there are Q waves or low R waves in the anterior leads.

i. the largest R in I or aVL $\geq$ an age and gender dependent limit (LIM1 and LIM2 respectively)

ii. |S| in V1 or V2 $\geq$ an age and gender dependent limit (LIM3)

iii. R in V5 or V6 $\geq$ an age and gender dependent limit (LIM4)

iv. the Lewis Index (RI + |S|III) - (RIII+ |S|I) > an age and gender dependent limit (for age 17 and over only) (LIM5)

v. the Sokolow Lyon Index |SV1| + RV5 > an age and gender dependent limit (for age 17 and over only) (LIM6)

Table of gender and age dependent limits for criterion A.
All figures are in millivolts.

	Birth	17 years		50 years	
		Male	Female	Male	Female
LIM1	1.3	1.5	1.5	1.6	1.4
LIM2	0.9	1.1	0.9	1.3	1.2
LIM3	3.0	4.0	3.5	2.5	2.0
LIM4	3.25	4.0	2.5	2.5	2.2
LIM5	-	2.5	2.0	2.0	1.8
LIM6	-	5.0	4.25	4.5	3.75

A complete table is too detailed to print.

B. (1-4 points)

(a) In any of I, aVL, V5 or V6

i. ST ≤ -0.02 mV and ST slope is downward sloping
ST ≤ -0.05 mV and ST slope is flat or downward sloping

ii. ST - T- > 0.1 mV

iii. T- < -0.2 mV with T+ < 0.15 mV

iv. R or R' > 1.0 mV

v. there are no pathological Q waves in the lateral leads

vi. QRS < 120 ms

Score 4 points if i-vi are true

Score 2 points if i, ii, iii, v, vi are true

(b) If (a) is not true then consider:

i. ST or T changes in the lateral leads

ii. A (i or iv is true)

iii. A (ii, iii or v) is true and not anterior infarction

iv. A (ii, iii or v) is true and anterior infarction

v. QRS < 120 ms

Score 2 points if i, v and (ii or iii)

Score 1 point if i, iv and v

Note: If B(a) or B(b) is true, deduct 2 points if there is inferior infarction with T- aVF < -0.05 mV.

C. (2 points)

i. the P wave flag is set

and ii. the terminal amplitude of P in V1 < -0.11 mV

and iii. the terminal duration of P in V1 ≥ 40 ms

If C is not true, score 1 if atrial fibrillation or atrial flutter is present.

D. (2 points)
- i. inferior infarction has not been detected
- and ii. -120° < frontal QRS axis < -30°

E. (1 point)
- i. the QRS duration in lead V5 or V6 ≥ 100 ms
- and ii. RBBB of any type is not present

F. (1 point)
- i. the intrinsicoid deflection in V5 or V6 ≥ 60 ms
- and ii. there are no pathological Q waves (see *Myocardial Infarction* section) in the corresponding lead

STATEMENTS

1. Left ventricular hypertrophy

(a) score ≥ 5 points

2. Possible left ventricular hypertrophy

(a) 4 ≤ score < 5 points and there are ST or T abnormalities in the lateral leads

3. LVH with secondary repolarization abnormality

- i. 1(a) is true
- and ii. B(a) is true

4. Possible LVH with secondary repolarization abnormality

- i. 2(a) is true
- and ii. B(a) is true

5. Left ventricular hypertrophy by voltage only

- i. LVH score ≥ 4
- and ii. criteria B-F are false
- and iii. there are no lateral ST-T changes

6. Borderline high QRS voltage - probable normal variant

This statement replaces 1 or 2 if the following are true:

- i. the LVH score ≤ 5
- and ii. any part of A above is true
- and iii. there is no BVH
- and iv. the patient is less than 35 years old
- and v. there are no ST-T changes
- and vi. there are no ST-T reasons for LVH set

RIGHT VENTRICULAR HYPERTROPHY

If WPW has been detected, this section is omitted.

The criteria for RVH are in the form of points awarded for each test. The points are totalled to give a final score.

The upper limits of normal voltage used for R and S amplitudes in the diagnosis of right ventricular hypertrophy are age dependent and can be made available in the form of continuous equations. A complete set of equations is too complex to include but as an example, the upper limit of S wave amplitude in Lead I is presented. The equation is valid from birth to 30 days.

$$LIM1 = \{40 - 0.267 \times Age(days)\}^2 \ \mu V$$

The following table is a guide to the various limits used in this section. Adult criteria are obtained using the higher values while pediatric criteria are derived from an age dependent value intermediate to the two lower limits.

Table of age dependent limits for criteria below.

	Birth	Adolescence	Age 60
LIM1	1.6 mv	0.482	0.36
LIM2	2.5 mv	1.5	
LIM3	3.14 mv	0.78	0.56
LIM4	2.17 mv	1.6	
LIM5	10.9	1.1	
LIM6	204°	90°	

For clarity, the criteria describe discrete thresholds and integer scores. However, as in other parts of the program, the discrete thresholds have been replaced by smooth continuous functions which return continuous scores. These are combined, where required, with other criteria using algebraic rules and the resulting overall score is used to determine the diagnostic statement that is output.

CRITERIA

A. 2 points)
- i. in lead I, either S or S' > LIM1
- and ii. | lead I, R > 0.1 mV
- and iii. in Lead I, |S| > R or |S'| > R'

B. (3 points)
- i. in lead I, either S or S' > 2.0*LIM1 with R > 0.1 mV(2.723 mV⟶1.0 mV)
- or ii. in V5, either S or S' > LIM2
- or iii. in V5, max (S,S') > max (R,R') and max (S,S') > 0.6LIM2

Note: If both A and B are true, count only B.

C. (3 points)
- i. in lead V1, the R or R' amplitude > LIM3
- and ii. T+ in V1 ≤ 0.7 mV (age 12-30), or 0.5 mV (age ≥ 30)
- or iii. In V4R, R > LIM4 or R' > 0.7 mV
- and iv. T+ in V4R ≤ 0.7 mV

D. (1 point)

R' > 0.1 mV and R' > R in lead V1 and age ≥16 years

E. (2 points)
- i. in V1, the R/|S| amplitude ratio ≥ LIM5 with S > 0.1 mV
- or ii. in V1, Q and S = 0 mV and age > 5 years
- and iii. in V1, either R or R' > 0.4 mV
- and iv. T+ amplitude in V1 ≤ 0.5 mV

F. 2 points)
- i. in V1, |Q| > 0.1 mV and Q ≥ 25 ms, and R ≥ 0.25 mV with R-STj ≥ 0.04 mV and S = 0 mV
- or ii. in V1, |S| > 0.1 mV and S > 25 ms, and R' > 0.25 mV with R'-STj > 0.04 mV, and R < 0.075 mV

G. (1 point)

in aVF, the P+ amplitude ≥ 0.3 mV

H. (0.5 point)
- i. in aVF, the ST junction is negative
- or ii. in aVF, T- < -0.1 mV, and the T wave is not (biphasic, starting positive)

J. (1 point)

(a)
- i. in V2, STj < 0.02 mV with downward slope < -5
- and ii. in V2, T- < -0.1 mV
- and iii. age ≥ 5 years

K (1 point)

LIM6 < QRS axis < 270°

L. (0.5 point)

LIM6 + 20° < QRS axis < 270°

M. (1 point)
- i. in all the leads I, II, and III, |S| > 0.2 mV
- and ii. QRS axis > 0°

STATEMENTS

1. Right ventricular hypertrophy

(a) Score ≥ 5 points

2. Possible right ventricular hypertrophy

(a) 4.5 ≤ score < 5 points

3. RVH with secondary repolarization abnormality

(a) 1(a) is true

and (b) the following is true in V1 or V2 or aVF, the latter if 75° < QRS axis ≤ 180°

i. marked downward ST slope

ii. ST < -0.05 mV

iii. T- < -0.2 mV

4. Possible RVH with secondary repolarization abnormality

(a) 2(a) is true

and (b) the following is true in V1 or V2 or aVF, the latter if 75° < QRS axis ≤ 180°

i. marked downward ST slope

and ii. ST < -0.05 mV

and iii. T- < -0.2 mV

BIVENTRICULAR HYPERTROPHY

STATEMENTS

If LBBB or WPW is set true, omit this section.

1. Biventricular hypertrophy

	(a)		i.	LV hypertrophy score ≥ 5 points
		and	ii.	RV hypertrophy score ≥ 5 points
or	(b)			the maximum QRS vector > an age dependent limit A (see table)
or	(c)		i.	LV hypertrophy score ≥ 11
		and	ii.	the maximum QRS vector (in I, aVF, V2) > age dependent limit B (see table)

2. Possible biventricular hypertrophy

	(a)			statement 1 is not true
and	(b)		i.	LV hypertrophy score ≥ 4
		and	ii.	RV hypertrophy score ≥ 4

3. BVH with secondary repolarization abnormality

	(a)			statement 1 is true
and	(b)		i.	LVH criterion B(a) is true
		or	ii.	RVH criterion 3(b) is true

4. Possible BVH with secondary repolarization abnormality

	(a)			statement 2 is true
and	(b)		i.	LVH criterion B(a) is true
		or	ii.	RVH criterion 4(b) is true

Table of age dependent limits for max QRS vector

	Age < 30	30 ≤ Age < 40	Age ≥ 40
LIMIT A	6.0 mV	5.0 mV	4.5 mV
LIMIT B	5.5 mV	4.5 mV	4.0 mV

7 Myocardial Infarction

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There are two types of criteria used to determine infarction. The first type uses criteria for acute ST elevation myocardial infarction (STEMI) and the second uses criteria based on Q waves and ST-T amplitudes.

There is one statement output if STEMI is detected and the Q wave criteria are not met in the corresponding leads, namely:

*** **CONSIDER ACUTE STEMI** ***

This STEMI statement will be output if any of the following statements appear on the report:-

- **++ ST elevation, CONSIDER ACUTE INFARCT**
- **POSSIBLE ACUTE ++ INFARCT**
- *** **++ INFARCT - POSSIBLY ACUTE** ***

Where ++ can be Inferior, Lateral, Anteroseptal Anterior, Septal, Posterior, Anterolateral or Extensive.

If Q waves are detected, then one of a number of statements may be output, e.g.

*** **INFERIOR INFARCT – POSSIBLY ACUTE** ***

The criteria for these statements are given in detail in this chapter.

STEMI CRITERIA

STEMI criteria are based on the recommendations[1] of the American College of Cardiology (ACC) and the European Society of Cardiology (ESC) for impending myocardial infarction. These criteria are based on the ST amplitude in two contiguous leads and have been extended to include improved criteria that are age and gender dependent. The new criteria use continuous equations for upper limits of normal ST amplitudes as well as |ST/T| and |S/ST| ratios and |Q| and |S| amplitudes[2].

The upper limits of normal ST amplitudes are determined from a set of equations. There is a different equation for each lead. As an example, the equation for lead V1 for male patients is given here.

Age (years)	Limit in µV
20 ≤ age ≤ 60	(-1.0) * age (in years) + 190
> 60	(-1) * 60 + 190 = 130
< 20	(-1) * 20 + 190 = 170

For female patients, a constant value is used as a limit across all ages. The constant is lead dependent. For V1, the limit is 100µV.

These criteria are omitted under the following conditions:

- presence of WPW
- presence of LBBB
- QRS duration > 180 ms
- age ≤ 18
- presence of IVCD and overall QRS duration > 140 ms (except if very high ST values for leads where an individual lead QRS duration < 110 ms)

1. European Heart Journal 2000; 21:1502-13
2. Macfarlane PW et al. Modification of ACC/ECC Criteria for Acute Myocardial Infarction. *J Electrocardiol*. 2004;37(suppl):98-103

Q WAVE CRITERIA

Omit this section if WPW is present.

Omit leads V2 - V4 if LBBB is present.

Statements mentioning myocardial infarction are not output in the pediatric age group, in which criteria for abnormal Q waves are checked and if any are found to be true, the statement “ABNORMAL VENTRICULAR CONDUCTION PATHWAYS” is produced.

It should also be noted that neural network software is used in addition to the criteria listed overleaf.

A neural network utilizing 9 input measurements, namely the Q amplitude and duration as well as the Q/R ratio in Leads II, III and aVF, has been trained to check for the presence of inferior myocardial infarction. However, the output from the network is not used in isolation. It is combined with the diagnosis made by the deterministic criteria listed in the following pages.

If the neural network detects inferior infarction, it is given a level of PROBABLE infarction. The level of certainty of the deterministic criteria is then compared with the neural network level and whichever is the higher is retained in the diagnosis. In addition, however, a neural network diagnosis of inferior infarction in the absence of deterministic criteria for infarction results in further checks being made to ensure that a Q wave is indeed present in aVF. This is to ensure that maximum specificity is obtained.

In the case of anterior myocardial infarction, a similar hybrid approach has been adopted. In this case, however, the network has 42 inputs. There are six measurements from each of 7 leads, namely, I, aVL, and V2-V6. These six measurements consist of the Q amplitude and duration, the R wave amplitude, the ST amplitude and the maximum positive and minimum negative T wave amplitudes. However, if the standard criteria listed for the different forms of anterior infarction, e.g. anteroseptal, anterior and septal, are already positive, then the neural network is not utilized. If conventional criteria are negative, then the neural network diagnosis is used. In this case, a check has to be made to see whether there are indeed Q waves or whether there are low R waves so that the appropriate reason statement can be produced.

For clarity, the criteria describe discrete thresholds and integer scores. However, as in other parts of the program, the discrete thresholds have been replaced by smooth continuous functions which return continuous scores. These are combined, where required, with other criteria using algebraic rules and the resulting overall score is used to determine the diagnostic statement that is output.

CRITERIA: Q WAVES IN INFERIOR AND LATERAL LEADS

Q1		(a)		i.	Q > 35 ms and |Q/R| > 1/5
			or	ii.	Q > 40 ms
			or	iii.	T axis < 0, and Q > 28 ms, and |Q/R| > 1/4 in aVF
	and	(b)			|Q| > 0.09 mV
	and	(c)			peak to peak QRS > 0.15 mV
Q2		(a)		i.	Q > 35 ms and |Q/R| > 1/5
			or	ii.	Q > 30 ms and |Q/R| > 1/3
	and	(b)			|Q| > 0.2 mV
	and	(c)			peak to peak QRS > 0.15 mV
Q3		(a)			Q > 26 ms and |Q/R| > 1/5
	and	(b)			|Q| > 0.14 mV
	and	(c)			peak to peak QRS > 0.15 mV
Q4		(a)		i.	Q ≥ 30 ms and T- < -0.1 mV
			or	ii.	|Q/R| > 1/3 and Q > 20 ms and age > 20
	and	(b)			|Q| > 0.075 mV
	and	(c)			peak to peak QRS axis > 0.2 mV
	and	(d)		i.	T- < -0.05 mV
			or	ii.	ST > 0.06 mV
Q5		(a)			|Q/R| > 1/4 in II and |Q| > 0.1 mV
		(b)			QRS axis < 0
		(c)			age > 20 years
Q6		(a)		i.	R amplitude in II < R amplitude in III
			and	ii.	QRS axis ≤ -30
			and	iii.	R < 0.20 mV in III
	or	(b)		i.	Q ≥ 15 ms and R < 0.1 mV and S > 20 ms in aVF
			and	ii.	peak-peak QRS > 0.15 mV in aVF
Q7		(a)			T axis < -10
		(b)			R < 0.90 mV in II
		(c)			|Q/R| > 1/5 in any 2 of II, III, or aVF

Similar criteria apply when a small primary r is present. In this case, S replaces Q and R' replaces R.

INFERIOR INFARCTION

STATEMENTS

The tests for Q1 to Q4 are carried out on II, III, and aVF. The following statements therefore refer to findings in these leads.

1. *** INFERIOR INFARCT - POSSIBLY ACUTE ***

A. Presence of Q waves

	(a)		i.	there are two or more Q1
		or	ii.	there is at least one Q1 and one Q2
or	(b)		i.	there is one Q1 and at least one Q3 or Q4
		or	ii.	there are two or more Q2
		or	iii.	there is one Q2 and one Q3
		or	iv.	there is one Q1 from II or aVF
		or	v.	there is one Q5
		or	vi.	there is one Q2 and one Q4
		or	vii.	there are two or more Q3 with |Q/R| > 1/4
		or	viii.	there is one Q6 or one Q7

and B. Acute ST elevation MI suspected

(a) the STEMI criteria are met

However if there is ST depression in V2 or there is very high ST elevation in II, III or aVF, the STEMI statement takes precedence.

2. Inferior infarct - age undetermined

	(a)	1A(a) is true
and	(b)	STEMI criteria not met

3. Possible inferior infarct - age undetermined

	(a)	1A(a) is false and 1A(b) is true
and	(b)	STEMI criteria not met

4. Abnormal ventricular conduction pathways

	(a)	if any of the previous statements is true
and	(b)	the age of the patient is less than 20 years

Replace the previous statement with this one.

INFERIOR INFARCTION STATEMENT ADDITION

5. Q waves may be due to cardiomyopathy

	(a)	any of the inferior infarction statements is set
and	(b)	there is a clinical classification of cardiomyopathy
and	(c)	there is no T wave inversion in II or aVF

LATERAL INFARCTION

STATEMENTS

The tests for Q1 to Q4 are carried out on I, aVL, V5, V6.

The following statements therefore refer to findings in these leads.

1. *** LATERAL INFARCT - POSSIBLY ACUTE ***

A. Presence of Q waves

	(a)		i.	there are two or more Q1
		or	ii.	there is one Q1 and at least one Q2
or	(b)		i.	there is one Q1 and at least one Q3 or Q4
		or	ii.	there are two or more Q2
		or	iii.	there is one Q2 and one Q3
		or	iv.	there is one Q2 and one Q4
		or	v.	there are two or more Q3 with |Q/R| > 1/4
		or	vi.	there is one or more Q1 from I, V5 or V6

and B. Acute ST elevation MI suspected

(a) the STEMI criteria are met

However if there is very high ST elevation in I, aVL, V5 or V6, the STEMI statement takes precedence.

2. Lateral infarct - age undetermined

	(a)	1A(a) is true
and	(b)	STEMI criteria not met

3. Possible lateral infarct - age undetermined

	(a)	1 A(a) is false and 1A(b) is true
and	(b)	STEMI criteria not met

4. Abnormal ventricular conduction pathways

	(a)	if any of the previous statements is set true
and	(b)	the age of the patient is less than 20 years

Replace the previous statement with this one.

LATERAL INFARCTION STATEMENT ADDITION

5. Q waves may be due to cardiomyopathy

	(a)	any of the lateral infarction statements is set
and	(b)	there is a clinical classification of cardiomyopathy
and	(c)	there is no T wave inversion in the lateral leads

CRITERIA: Q WAVES IN ANTEROSEPTAL, ANTERIOR OR SEPTAL LEADS

VQ1					
		(a)		i.	|Q| > 0.2 mV or |Q| > 0.15 mV and |Q/R| > 1/2
			and	ii.	Q > 30 ms
			and	iii.	peak to peak amplitude > 0.2 mV
	or	(b)		i.	R = 0
			and	ii.	|S| > 0.2 mV
			and	iii.	S > 30 ms
			and	iv.	peak to peak amplitude > 0.2 mV
VQ2					
		(a)		i.	|Q| > 0.14 mV
			and	ii.	Q > 15 ms
			and	iii.	|Q/R| > 1/4
			and	iv.	peak to peak amplitude > 0.2 mV
	or	(b)		i.	R < 0.065 mV
			and	ii.	|S| > 0.14 mV
			and	iii.	S > 15 ms
			and	iv.	|S/R'| > 1/4
VQ3					
		(a)		i.	R < 0.11 mV
			and	ii.	R' < 2R amplitude, or RBBB is present
			and	iii.	|R/S| < 0.125
			and	iv.	the peak to peak amplitude > 0.2 mV
			and	ii.	RVH is not present
VQ4					
		(a)		i.	R in V(n) - R in V(n+1) > 0.05 mV in the adjacent precordial lead, (e.g. RV3 < RV2)
			and	ii.	R < 0.3 mV in those two leads
			and	iii.	R' < R in those two leads
QRVH					
		(a)		i.	R > 0.3 mV with S = 0 mV or R < 0.1 mV with R' > 0.3 mV
			and	ii.	RBBB or IVCD are not present
			and	iii.	ST in V2 ≤ 0.12 mV or ST < 1/2 T+
	or	(b)		i.	R < 0.3 mV or S is not 0 mV
			and	ii.	in lead I, S or S' < -0.5 mV
			and	iii.	there is a clinical classification of congenital heart disease, rheumatic heart disease, pericarditis, respiratory disease, pulmonary embolism, post cardiac surgery, cardiomyopathy or other/not known
			and	iv.	RBBB or IVCD are not present
PRWP		(a)		i.	Male and R V3 < 0.3 mV and R' V3 < 0.3 mV
			or	ii.	Female and R V3 < 0.25 mV and R' V3 < 0.25 mV
	and	(b)			none of VQ1 - VQ4 is true

ANTEROSEPTAL MYOCARDIAL INFARCTION

STATEMENTS

The tests for VQ1 - VQ4 are applied to V2 - V4.

The following statements therefore apply to findings in these leads.

1. *** ANTEROSEPTAL INFARCT - POSSIBLY ACUTE ***

A. Presence of Q waves

(a) VQ1 is true for V2 and one of V3, V4 with QRVH false in V1

or (b) i. one VQ1 is true, and there is a VQ in V2 and in V3 or V4 with QRVH false in V1

or ii. VQ2(a) is true in V2 and one of V3, V4 with QRVH false in V1

or iii. VQ2(b) is true in V2 and one of V3, V4

and B. Acute ST elevation MI suspected

(a) the STEMI criteria are met

However, if there is very high ST elevation in V1, V2, V3 or V4, the STEMI statement takes precedence.

2. Anteroseptal infarct - age undetermined

(a) 1A(a) is true

and (b) STEMI criteria not met

3. Possible anteroseptal infarct - age undetermined

(a) 1A(a) is false and 1A(b) is true

and (b) STEMI criteria not met

4. Cannot rule out anteroseptal infarct - age undetermined

(a) if any of the statements 1-3 is set true

and (b) LVH is present

and (c) ST < 1/2 T+ in V2 and V3

and (d) there is not a clinical classification of either congenital heart disease or rheumatic heart disease

and (e) the age of the patient is 20 years or over

and (f) VQ1 is false in both V3 and V4

and (g) there is not clockwise cardiac rotation

The above statement replaces any of 1-3, if true.

5. Abnormal ventricular conduction pathways

(a) any of the above statements is true

and (b) the age of the patient is less than 20 years

The above statement replaces any of 1-4, if true.

6. Anteroseptal QRS changes may be due to ventricular hypertrophy

	(a)	any of the above statements is true
and	(b)	there is moderate or high T+ in V2 - V4
and	(c)	ST < 1/2 T+ in V2, V3
and	(d)	there is not a clinical classification of myocardial infarction but there is of rheumatic heart disease

The above statement replaces any previous one, if true.

7. Anteroseptal QRS changes may be due to corrected transposition

	(a)	any of the above statements is true
and	(b)	there is moderate or high T+ in V2 - V4
and	(c)	ST < 1/2 T+ in V2 and V3
and	(d)	there is not a clinical classification of myocardial infarction but there is of congenital heart disease

The above statement replaces any previous one, if true.

8. QRS changes may be due to LVH but cannot rule out anteroseptal infarct

	(a)	if any statements 1-4 is set true
and	(b)	LVH is present with secondary ST-T changes and |S| in V2 > 2.0 mV
and	(c)	ST < 1/2 T+ in V2 and V3
and	(d)	there is not a clinical classification of either congenital heart disease or rheumatic heart disease
and	(e)	the age of the patient is 20 years or over
and	(f)	there is not clockwise cardiac rotation and VQ1 is false in V4

The above statement replaces any of 1-4, if true.

9. Poor R wave progression - cannot rule out anteroseptal infarct

	(a)	if any statements 1-4 is set true
and	(b)	ST < 1/2 T+ in V2 and V3
and	(c)	clockwise cardiac rotation is true, and VQ1 false in V4

The above statement replaces any of 1-4, if true.

10. Poor R wave progression consistent with pulmonary disease

	(a)	9(a) to (c) are true
and	(b)	there is a clinical classification of respiratory disease but not of myocardial infarction

The above statement replaces any of 1-4, if true.

ANTEROSEPTAL INFARCTION STATEMENT ADDITION

11. Q waves may be due to cardiomyopathy

	(a)	any of the anteroseptal infarction statements is set
and	(b)	there is a clinical classification of cardiomyopathy
and	(c)	there is moderate or high T+ in V2 - V4

ANTERIOR MYOCARDIAL INFARCTION

STATEMENTS

The tests for VQ1 - VQ4 are applied to V3, V4. The following statements therefore apply to findings in these leads.

1. *** ANTERIOR INFARCT - POSSIBLY ACUTE ***

A. Presence of Q waves

	(a)		VQ1 is true for V3 and V4 with QRVH false in V1
or	(b)	i.	VQ1 is true for V3 or V4 with QRVH false in V1
	or	ii.	VQ4 is true in V2, V3 or V3, V4
	or	iii.	VQ2(a) is true in V3 or V4 with QRVH false in V1
	or	iv.	VQ2(b) or VQ3 is true in V3 or V4
	or	v.	VQ4 is true for V2, V3 or V3, V4 except for females < 50
	or	vi.	PRWP is true and R < 0.4 mV in I and not RVH and (|S| < 0.15 MV in I or R > 0.4 mV in V4 or T < 0.05 mV in V2-V4)
	or	vii.	PRWP is true and R > 0.4 mV in I and [(ST > 0.05 mV and ST > T+/2 in V3 or V4) or (LVH is present and R < 0.15 mv in V4)]

and B. Acute ST elevation MI suspected

(a)		the STEMI criteria are met
		However, if there is very high ST elevation in V1, V2, V3 or V4, the STEMI statement takes precedence

2. Anterior infarct - age undetermined

	(a)	1A(a) is true
and	(b)	STEMI criteria not met

3. Possible anterior infarct - age undetermined

A.		(a)	1 A(a) is false and 1 A(b) is true
	and	(b)	STEMI criteria not met
or B.		(a)	if statement 1 or 2 is true
	and	(b)	ST < 1/2 T+ in V3 and V4
	and	(c)	clockwise rotation is true, and VQ1 is false in V4

If 3B is true, statement 3 replaces statement 1 or 2.

4. Cannot rule out anterior infarct - age undetermined

	(a)	if any of the statements 1-3 is true
and	(b)	LVH is present
and	(c)	ST < 1/2 T+ in V3 and V4
and	(d)	there is not a clinical classification of either congenital heart disease or rheumatic heart disease
and	(e)	the age of the patient is 20 years or over
and	(f)	VQ1 is false in both V3 and V4
and	(g)	there is not clockwise cardiac rotation
and	(h)	VQ2 or VQ4 is true for V3

The above statement replaces any of 1-3, if true.

5. Abnormal ventricular conduction pathways

	(a)	any of the above statements is true,
and	(b)	the age of the patient is less than 20 years

The above statement replaces any of 1 - 4, if true.

6. Anterior QRS changes may be due to ventricular hypertrophy

	(a)	any of the above statements is true
and	(b)	there is moderate or high T+ in V3, V4
and	(c)	ST < 1/2 T+ in V3 and V4
and	(d)	there is not a clinical classification of myocardial infarction but there is of rheumatic heart disease.

The above statement replaces any previous one, if true.

7. Anterior QRS changes may be due to corrected transposition

	(a)	if any of the statements is true
and	(b)	there is moderate or high T+ in V3 and V4
and	(c)	ST < 1/2 T+ in V3, V4
and	(d)	there is not a clinical classification of myocardial infarction but there is of congenital heart disease

The above statement replaces any previous one, if true.

8. QRS changes V3/V4 may be due to LVH but cannot rule out anterior infarct

	(a)	if any of the statements 1-4 is true
and	(b)	LVH is present with secondary ST-T changes and |S| in V2 > 2.0 mV
and	(c)	ST < 1/2 T+ in V3 and V4
and	(d)	there is not a clinical classification of either congenital heart disease or of rheumatic heart disease
and	(e)	the age of the patient is 20 years or over
and	(f)	there is not clockwise cardiac rotation, and VQ1 is false in V3 and V4

The above statement replaces any of 1 - 4, if true.

9. Anterior QRS changes are probably related to pulmonary disease

(a) if any of statements 1-4 are true
and (b) there is a clinical classification of respiratory disease but not of myocardial infarction

The above statement replaces any of 1 - 4, if true.

10. Poor R wave progression - probable normal variant

(a) i. VQ4 or PRWP is true
and ii. R or R' in I > 0.4 mV
and iii. there is moderate or high T+ in V2 - V4 or moderate, but not high, T- in V2 - V4
and iv. there is small or moderate, but not high, ST elevation V2 - V4
and v. $R \leq 0.6$ mV in V4 for males
or $R \leq 0.4$ mV in V4 for females
or S amp > R amp + 0.4 mV
and vi. there is not LVH
and vii. there is no inferior or lateral infarction
or (b) i. VQ4 or PRWP is true
ii. R or R' in I > 0.4 mV
iii. there is no T+ in V2 - V4
iv. there is no significant ST elevation V2 - V4
v. there is not LVH
vi. there is no inferior or lateral infarction

ANTERIOR INFARCTION STATEMENT ADDITION

11. Q waves may be due to cardiomyopathy

(a) any of the Anterior Infarction statements is set
and (b) there is a clinical classification of cardiomyopathy
and (c) there is moderate or high T+ in V3, V4

SEPTAL INFARCTION

STATEMENTS

The tests for VQ1 and VQ2a are applied to V1, V2.
The following statements therefore apply to findings in these leads.

1. *** SEPTAL INFARCT - POSSIBLY ACUTE ***

A. Presence of Q waves

(a) VQ1 is true for V2 with QRVH false in V1

or (b) i. there is VQ2(a) in V2 with QRVH false in V1

and B. Acute ST elevation MI suspected

(a) the STEMI criteria are met

However, if there is very high ST elevation in V1, V2, V3 or V4, the STEMI statement takes precedence

2. Possible septal infarct - age undetermined

(a) 1 A(a) or (b) is true

and (b) STEMI criteria not met

3. Cannot rule out septal infarct - age undetermined

(a) any of statements 1-2 is true

and (b) LVH is present

and (c) ST < 1/2 T+ in V2

and (d) there is not a clinical classification of either congenital heart disease or rheumatic heart disease

and (e) the age of the patient is 20 years or over

The above statement replaces any of 1-2, if true.

4. Abnormal ventricular conduction pathways

(a) any of the above statements is true

and (b) the age of the patient is less than 20 years

The above statement replaces any of 1-3, if true.

5. Septal QRS changes may be due to ventricular hypertrophy

(a) any of the above statements is true

and (b) there is no T- in V2

and (c) ST < 1/2 T+ in V2 and there is not an age undetermined infarct

and (d) there is not a clinical classification of myocardial infarction but there is of rheumatic heart disease

The above statement replaces any previous one, if true.

6. Septal QRS changes may be due to corrected transposition

	(a)	any of the above statements is true
and	(b)	there is no T- in V2
and	(c)	ST < 1/2 T+ in V2 and there is not an age undetermined infarct
and	(d)	there is not a clinical classification of myocardial infarction but there is of congenital heart disease

The above statement replaces any previous one, if true.

7. QRS changes in V2 may be due to LVH but cannot rule out septal infarct

	(a)	any of the statements 1-3 is true
and	(b)	LVH is present with secondary ST-T changes and |Q| in V2 > 2.0 mV
and	(c)	ST < 1/2 T+ in V2
and	(d)	there is not a clinical classification of either congenital heart disease or rheumatic heart disease
and	(e)	the age of the patient is 20 years or over

The above statement replaces any of 1-3, if true.

8. Poor R wave progression - cannot rule out septal infarct

	(a)	if any of the statements 1 - 3 is true
and	(b)	ST < 1/2 T+ in V3 and V4
and	(c)	clockwise cardiac rotation is true, and VQ1 false in V4

The above statement replaces any of 1-3, if true.

9. Poor R wave progression may be due to pulmonary disease

	(a)	8(a) to (c) are true
and	(b)	there is a clinical classification of respiratory disease but not of myocardial infarction

The above statement replaces any of 1-3, if true.

SEPTAL INFARCTION STATEMENT ADDITION

10. Q waves may be due to cardiomyopathy

	(a)	any of the septal infarction statements are set
and	(b)	there is a clinical classification of cardiomyopathy
and	(c)	there is moderate or high T+ in V2

POSTERIOR MYOCARDIAL INFARCTION

CRITERIA:

PMI1:

	(a)		i.	R in V1 > 40 ms
		and	ii.	R in V1 > 0.8 mV
		and	iii.	T+ in V1 > 0.5 mV
and	(b)		i.	R in V2 > 40 ms
		and	ii.	R in V2 > 1 mV
		and	iii.	T+ in V2 > 0.8 mV

POSTERIOR INFARCTION STATEMENTS

If there are inferior or lateral infarct statements or RBBB or RVH, omit statement 1.

1. Possible posterior infarct - age undetermined

	(a)	PMI1 is true

POSTERIOR INFARCTION STATEMENT ADDITIONS

2 and 3 are additions to any inferior or lateral infarction statement only.

2. Possible posterior extension of infarct

	(a)	PMI1 is set true
and	(b)	there is inferior or lateral myocardial infarction

3. Tall R V1/V2 probably reflect the infarct

	(a)	**RVH** is true, with tall R in V1 or V2
and	(b)	there is inferior or lateral myocardial infarction
and	(c)	RBBB is not present

If 3 is true, then RVH is set false.

ANTEROLATERAL MYOCARDIAL INFARCTION

This section is entered if the following criteria are met.

CRITERIA

	(a)		i.	there is a Q1 in V5
		or	ii.	there is a Q2 in V5 with lateral myocardial infarction true
and	(b)		i.	there is a VQ1 or VQ2 in V4
		or	ii.	there is a VQ3 in V4 or VQ4 in V3, V4

Any anterolateral statement will suppress the separate lateral, anteroseptal, and anterior statements.

STATEMENTS

1. ***ANTEROLATERAL INFARCT - POSSIBLY ACUTE***

A. Presence of Q waves

	(a)		i.	in I, aVL, V5, V6 there are two or more Q1 or at least one Q1 and Q2
		or	ii.	VQ1 is true for (V2 and V3 or V4) or (V3 and V4) with QRVH false in V1
or	(b)		i.	in I, aVL, V5, V6 there is one Q1 and at least one Q3 or Q4
		or	ii.	in I, aVL, V5, V6 there are two or more Q2
		or	iii.	in I, aVL, V5, V6 there is one Q2 and one Q3
		or	iv.	one VQ1 is true, and there is a VQ in V2 and in V3 or V4 with QRVH false in V1
		or	v.	VQ1 is true for V3 or V4 with QRVH false in V1
		or	vi.	VQ4 is true for V2, V3 or V3, V4

and B. Acute ST elevation MI suspected

	(a)	the STEMI criteria are met However, if there is very high ST elevation in I, aVL, V5, V6, V1, V2, V3 or V4, the STEMI statement takes precedence

2. Anterolateral infarct - age undetermined

	(a)	1 A(a) is true
and	(b)	STEMI criteria not met

3. Possible anterolateral infarct - age undetermined

	(a)	1 A(a) is false and 1 A(b) is true
and	(b)	STEMI criteria not met

4. Abnormal ventricular conduction pathways

	(a)	if any of the previous statements is set true
and	(b)	the age of the patient is less than 20 years

ANTEROLATERAL INFARCTION STATEMENT ADDITION

5. Q waves may be due to cardiomyopathy

	(a)	any of the anterolateral infarction statements is set
and	(b)	there is a clinical classification of cardiomyopathy
and	(c)	there is moderate or high T+ in anterolateral leads

EXTENSIVE MYOCARDIAL INFARCTION

This section is entered if the following criteria are met.

CRITERIA

(a) there is inferior infarction
and (b) there is lateral infarction
and (c) there is anterior or anteroseptal infarction

STATEMENTS

1. *** EXTENSIVE INFARCT - POSSIBLY ACUTE ***

(a) i. there is inferior or lateral infarction with relevant Q1, Q2 true
and ii. there is anteroseptal infarction with relevant Q1, Q2 true
and (b) the STEMI criteria are met
However, if there is very high ST elevation in any lead, then the STEMI statement takes precedence

2. Extensive infarct - age undetermined

(a) i. there is inferior or lateral infarction with relevant Q1, Q2 true
and ii. there is anteroseptal infarction with relevant Q1, Q2 true
and (b) the STEMI criteria are not met

3. Possible extensive infarct - age undetermined

(a) weaker Q wave criteria are met in the inferior and anterolateral leads
and (b) the STEMI criteria are not met

EXTENSIVE INFARCTION STATEMENT ADDITION

4. Q waves may be due to cardiomyopathy

(a) any of the Extensive Infarction statements is set
and (b) there is a clinical classification of cardiomyopathy
and (c) T waves are not inverted

8 ST Abnormalities

Contents

- CRITERIA 8-2
- ST DEPRESSION 8-6

CRITERIA

There are two sets of criteria used to determine the presence of ST abnormalities. The first uses the criteria for acute ST elevation as used to indicate myocardial infarction (STEMI). This is described in Chapter 7, *Myocardial Infarction*. The second criterion uses a scoring system for the ST elevation and depression in each lead. This scoring system uses the limits of normal ST amplitudes and the slope of the ST segment to determine a score varying from -3.0 to 3.0. For ST elevation in adult ECGs, the limits used are the same as in the STEMI criteria and are dependent on age, gender and lead. For pediatric ECGs and ST depression, the limits used are dependent on the age of the patient and on the wall i.e., inferior, lateral or anterior. The score gives an indication of the degree of elevation or depression and is based on a smoothed function using multiple variables.

Using these criteria, there are three categories of ST elevation used to determine which statement is output. These are the STEMI elevation, marked ST elevation and moderate ST elevation. Marked and moderate elevation are defined as follows.

In the absence of LBBB, RBBB or any Q wave myocardial infarction,

Marked ST elevation is defined as:

1.
   (a) a high score for ST elevation in 2 or more of leads I, II, III, aVL, aVF, V5, V6
   and (b) i. there is no LVH
   or ii. there is a clinical classification of myocardial infarction
   or iii. there is a clinical classification of pericarditis
   or iv. the QRS axis is positive

or 2.
   (a) there is a high score for ST elevation in 2 or more of V2, V3, and V4
   and (b) i. there is no LVH
   or ii. there is a clinical classification of myocardial infarction
   or iii. there is a clinical classification of pericarditis

Moderate ST elevation is defined as:

1.
   (a) a moderate score for ST elevation in 2 or more of leads I, II, III, aVL, aVF, V5, V6
   and (b) i. there is no LVH
   or ii. there is a clinical classification of myocardial infarction
   or iii. there is a clinical classification of pericarditis
   or iv. the QRS axis is positive

or 2.
   (a) there is a moderate score for ST elevation in 2 or more of V2, V3, and V4
   and (b) i. there is no LVH
   or ii. there is a clinical classification of myocardial infarction
   or iii. there is a clinical classification of pericarditis

STATEMENTS (REASONS)

In the diagnostic output relating to ST abnormalities, there is a "reason" statement printed above or beside the diagnostic statement, e.g.

Inferior ST elevation

This is essentially integral to the diagnostic statement that follows, e.g.

Inferior ST elevation, CONSIDER ACUTE INFARCT

The following are the "reason" comments:

1. Inferior ST elevation

(a) Q wave inferior infarction is not true
and (b) there is acute, marked or moderate ST elevation in the inferior leads

2. Lateral ST elevation

(a) Q wave lateral and anterolateral infarction are not true
and (b) there is acute, marked or moderate ST elevation in the lateral leads

3. Anteroseptal ST elevation

(a) there is acute, marked or moderate ST elevation in the anteroseptal leads

4. Anterior ST elevation

(a) 3 is not true
and (b) there is acute, marked or moderate ST elevation in the anterior leads

5. Septal ST elevation

(a) 3 is not true
and (b) there is acute, marked or moderate ST elevation in the septal leads

6. Extensive ST elevation

(a) there is acute, marked or moderate ST elevation in the inferior leads
and (b) there is acute, marked or moderate ST elevation in the anterolateral leads

7. Anterolateral ST elevation

	(a)	there is acute, marked or moderate ST elevation in the anterolateral leads

Combinations of the above are possible, e.g.

Inferior and lateral ST elevation

8. Anteroseptal ST depression

	(a)	STj < -0.1 mV and STj ≤ T- + 0.05 mV in any of V1 - V6
and	(b)	there is ACUTE inferior MI
and	(c)	there is not RBBB
and	(d)	age ≥ 18 years

9. Marked precordial ST depression

	(a)	ST junction < -0.3 mV and the ST slope < 0 in any of V1 - V4 and also V5 or V6
and	(b)	there is no RBBB or LBBB
and	(c)	there is no LVH with repolarization
and	(d)	age ≥ 18 years

STATEMENTS

If any of 1 to 7 (or combinations) above is true, print one of the following.

1. , CONSIDER ACUTE INFARCT

	(a)	age ≥ 18 years
and	(b)	the STEMI criteria are met

2. suggests post operative pericarditis

	(a)	clinical classification includes post cardiac surgery
and	(b)	extensive ST elevation

3. - probable post operative pericarditis

	(a)	there is a clinical classification of post-operative cardiac surgery
and	(b)	there is ST elevation
and	(c)	statement 2 is false

4. suggests pericarditis

	(a)	statements 1 - 3 are false
and	(b)	there is marked inferior and anterolateral ST elevation

5. - consider pericarditis

	(a)	statements 1 - 4 are false
and	(b)	there is moderate inferior and anterolateral ST elevation

6. is consistent with pericarditis

	(a)		statements 1 - 3 are false
and	(b)		there is a clinical classification of pericarditis
and	(c)	i.	there is marked ST elevation
	or	ii.	there is moderate ST elevation in anterolateral and inferior leads

7. - cannot rule out myocardial injury

	(a)		statements 1 - 3 are false
and	(b)	i.	LVH is present
	and	ii.	there is marked ST elevation in at least 2 of the inferior or lateral leads
	and	iii.	QRS axis > 0
	and	iv.	there is not a clinical classification of myocardial injury or pericarditis or post-operative cardiac surgery

8. suggests early repolarization

	(a)	statements 1 - 7 are false
and	(b)	there is marked ST elevation

9. - possible early repolarization

	(a)	statements 1 - 8 are false
and	(b)	there is moderate ST elevation

ST DEPRESSION

If either of the following sets of criteria is true, then reason 8 or 9 is printed together with the appropriate statement 10 or 11 respectively.

10. is probably reciprocal to inferior infarct

	(a)		age ≥ 18 years
and	(b)		there is an acute inferior infarct
and	(c)		in V1 - V6 ST < -0.1 mV and ST ≤ T- + 0.05 mV
and	(d)		there is not RBBB

11. , CONSIDER ACUTE INFARCT

	(a)			age ≥ 18 years
and	(b)		i.	ST < -0.3 mV in any of V1 - V4 with corresponding ST slope negative, and RBBB is false
		or	ii.	ST < -0.3 mV in V5 or V6 with corresponding ST slope negative, and LVH with secondary repolarization abnormality and LBBB are not present

9 ST-T Changes

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- STATEMENTS (REASONS) 9-3
- STATEMENTS 9-4

Acute ST-T Changes

*** ACUTE MI / ISCHEMIA ***

This statement will be output if any of the following statements appear on the report:

- **Marked precordial ST depression, CONSIDER ACUTE INFARCT**
- **suggest myocardial infarct**
- **may be due to myocardial infarct or CVA**
- **suggest myocardial injury/ischemia**

The presence of the statement *** **CONSIDER ACUTE STEMI** *** on the report will inhibit the output of the *** **ACUTE MI / ISCHEMIA** *** statement.

CRITERIA

The criteria for ST-T changes are essentially classical in nature relating to ST depression or T wave inversion. In practice, however, their logical relationship to diagnostic statements is somewhat involved. For this reason, a simplified version is set out below.

INFERIOR LEADS

(a) there is ST depression or T wave inversion in inferior leads
(b) there is not inferior myocardial infarction
(c) none of **WPW** or **LBBB** is true

LATERAL LEADS

(a) there is ST depression or T wave inversion in lateral leads
(b) there is not lateral infarction
(c) none of **WPW** or **LBBB** is true

ANTEROSEPTAL LEADS

(a) there is ST depression or T wave inversion in anteroseptal leads
(b) there is not (anterior) septal or anterior infarction
(c) none of **WPW**, **RBBB**, **RBBB with left anterior fascicular block**, **RBBB with left posterior fascicular block** or **Extensive IVCD** is true

ANTERIOR LEADS

(a) there are not ST-T changes in the anteroseptal leads
(b) there is ST depression or T wave inversion in the anterior leads
(c) none of **WPW**, **RBBB**, **RBBB with left anterior fascicular block**, **RBBB with left posterior fascicular block**, **Extensive IVCD** or **LBBB** is true

SEPTAL LEADS

(a) there are not ST-T changes in the anteroseptal or anterior leads
(b) there is ST depression or T wave inversion in the septal leads
(c) there is not anteroseptal or anterior or septal infarction
(d) none of **WPW**, **RBBB**, **RBBB with left anterior fascicular block**, **RBBB with left posterior fascicular block** or **Extensive IVCD** is true

ANTEROLATERAL LEADS

(a) there are ST and/or T wave changes in both anterior and lateral leads as defined above

EXTENSIVE

(a) there are ST and/or T wave changes in the inferior leads and either the anterolateral or lateral leads together with septal, anteroseptal or anterior leads

STATEMENTS (REASONS)

There are several possible "reasons" that can precede the main part of the diagnostic statement but which are an integral part. For example, "**Inferior ST-T changes**" may precede the statement "**are non specific**" to produce "**Inferior ST-T changes are non specific**". Thus statements in this section of the manual are built up from a "reason" and a diagnostic component. The following summarize the reasons:

1. *** ST changes**

   The location of the abnormality, denoted *, can be chosen from the following: Inferior, Lateral, Anteroseptal, Anterior, Septal, or Anterolateral

2. **ST junctional depression**
3. **Extensive ST changes**
4. *** T wave changes**

   The location of the abnormality, denoted *, can be chosen from the following: Inferior, Lateral, Anteroseptal, Anterior, Septal, or Anterolateral

5. **Extensive T wave changes**
6. *** ST-T changes**

   The location of the abnormality, denoted *, can be chosen from the following: Inferior, Lateral, Anteroseptal, Anterior, Septal, or Anterolateral

7. **Extensive ST-T changes**

Various combinations can be selected, e.g. **Inferior/lateral**

STATEMENTS

If any of the previous "reasons" is true, it is printed together with one of the following statements, which are presented here in almost a hierarchical form, i.e. a statement towards the end of the list would only be printed if those near the top were not relevant. In the interest of brevity there are marked simplifications in presenting the list.

An example of the output in this section is as follows:

Lateral ST-T changes may be due to hypertrophy and/or ischemia

In the pediatric age range, statements involving "Myocardial Ischemia" are suppressed and are replaced by a more appropriate statement, e.g. "**Non-specific changes**".

1. are nonspecific

	(a)			there are T wave changes in any lead group
and	(b)			there is demand pacemaker activity

2. may be due to hypertrophy and/or ischemia

	(a)			LVH or RVH or BVH
and	(b)			ST-T abnormalities
and	(c)		i.	male ≥ 30
		or	ii.	female ≥ 40
and	(d)			patient is not on digitalis

3. may be due to hypertrophy and/or ischemia/digitalis effect

	(a)			2(a)(b)(c) are true
and	(b)			patient is on digitalis

4. are probably due to ventricular hypertrophy

	(a)			LVH or RVH or BVH
and	(b)			ST-T abnormalities
and	(c)		i.	male < 30
		or	ii.	female < 40
and	(d)			patient is not on digitalis

5. are probably due to ventricular hypertrophy/ digitalis effect

	(a)			4(a)(b)(c) are true
and	(b)			patient is on digitalis

6. may be due to myocardial ischemia

	(a)			there are ST-T changes in the lateral leads
and	(b)		i.	there is evidence of anterior or anteroseptal infarction with T wave inversion in the relevant leads
		or	ii.	there is inferior infarction with inferior T wave changes

7. suggest myocardial infarct

A.

(a) there is marked ST depression
and (b) patient is not on digitalis
and (c) there is not atrial flutter or atrial fibrillation
and (d) there is a clinical classification of myocardial infarction

or B.

(a) T- < -0.5 mV in V2 or V3 or V4
or (b) T- < -0.35 mV in aVF

8. are consistent with pulmonary embolism

(a) clinical classification is pulmonary embolism
and (b) patient is not on digitalis
and (c) i. 7(a)(c) are true and there are ST-T changes in the (antero) septal leads
or ii. there are moderate ST-T changes in certain combinations of leads

9. suggest myocardial injury/ischemia

(a) 7(a)(b)(c) are true
and (b) clinical classification is not myocardial infarction, pulmonary embolism or post cardiac surgery in the presence of certain groups of ST-T changes

10. are probably due to cardiac surgery

(a) clinical classification is post cardiac surgery
and (b) i. there is widespread T wave inversion
or ii. there are T wave changes in at least two groups of leads

11. may be due to myocardial infarct or CVA

(a) there is T wave inversion in the lateral or anteroseptal leads
and (b) T- < -1.0 mV in V3, V4 or V5

12. are consistent with endocrine disease

(a) T wave abnormalities (but not in anteroseptal leads only)
and (b) clinical classification is endocrine disease
and (c) the heart rate < 60
and (d) the patient is not on digitalis

13. are possibly secondary to hypertension

(a) T wave abnormalities in the inferior and/or lateral leads
and (b) clinical classification is hypertension
and (c) patient is not on digitalis

14. are possibly secondary to hypertension/digitalis effect

	(a)	13(a) and (b) are true
and	(b)	patient is on digitalis

15. may be secondary to hypertension/ischemia

	(a)	T wave abnormalities including inferior and lateral leads in addition to T wave changes in other leads
and	(b)	clinical classification is hypertension
and	(c)	patient is not on digitalis

16. may be due to digitalis/hypertension

	(a)	15(a) and (b) are true
and	(b)	patient is on digitalis

17. are possibly secondary to congenital heart disease

	(a)	there are ST and/or T wave abnormalities
and	(b)	clinical classification is congenital heart disease
and	(c)	patient is not on digitalis

18. are possibly secondary to valvular heart disease

	(a)	there are ST and/or T wave abnormalities
and	(b)	clinical classification is rheumatic heart disease
and	(c)	patient is not on digitalis

19. are possibly secondary to valvular heart disease/digitalis

	(a)	18(a) and (b) are true
and	(b)	patient is on digitalis

20. are possibly secondary to respiratory disease

	(a)	there are ST or T wave changes in the inferior leads with or without other ST-T changes
and	(b)	clinical classification is respiratory disease
and	(c)	P+ amplitude in aVF > 0.3 mV
and	(d)	QRS axis > 60° if ST-T changes other than inferior are present
and	(e)	patient is not on digitalis

21. are normal for age

	(a)	T wave changes in (anterior) septal leads
and	(b)	age < 20 years

22. are normal for age and race

	(a)	21(a) is true
and	(b)	black with age < 40 years

23. may be normal for age

	(a)			T wave changes in the inferior leads
and	(b)		i.	the patient is female with age < 35 years
		or	ii.	the patient is male with age < 30 years
and	(c)			patient is not on digitalis
and	(d)			no previous statement is true and clinical classification is not myocardial infarction or ischemia

24. are consistent with digitalis effect

	(a)	female with age < 35 years or male with age < 30 years
and	(b)	no previous statement is true and clinical classification is not myocardial infarction or ischemia
and	(c)	patient is on digitalis
and	(d)	clinical classification is not pulmonary embolism or post cardiac surgery with certain groups of ST-T changes

25. suggest myocardial ischemia

	(a)	marked T wave abnormalities in any group or groups of leads
and	(b)	clinical classification is myocardial infarction or myocardial ischemia
and	(c)	patient is not on digitalis

26. suggest ischemia/ digitalis effect

	(a)	25(a) and (b) are true
and	(b)	patient is on digitalis

27. may be due to myocardial ischemia

	(a)	ST-T abnormalities in any group of leads
and	(b)	no previous statement true
and	(c)	patient is not on digitalis
and	(d)	clinical classification is not myocardial infarction or ischemia
and	(e)	age > 30 years if male or age > 40 years if female

28. suggest possible myocardial ischemia/ digitalis effect

	(a)	27(a)(b)(d)(e) are true
and	(b)	patient is on digitalis

29. are abnormal

	(a)	27(a) to (d) are true
and	(b)	age ≤ 30 years if male or age ≤ 40 years if female

30. are abnormal - possible digitalis effect

	(a)	29(a) and (b) are true
and	(b)	patient is on digitalis

31. are consistent with myocardial ischemia

	(a)	moderate ST and/or T wave abnormalities in any group or group of leads
and	(b)	clinical classification of myocardial infarction or myocardial ischemia
and	(c)	patient is not on digitalis

32. are consistent with ischemia/ digitalis effect

	(a)	31(a) and (b) are true
and	(b)	patient is on digitalis

33. - possible digitalis effect

	(a)	31(a) is true
and	(b)	31(b) is false and clinical classification is not normal
and	(c)	patient is on digitalis
and	(d	age > 30 years if male or age > 40 years if female

34. are borderline

	(a)	31(a) is true
and	(b)	clinical classification is normal
and	(c)	patient is not on digitalis
and	(d	age > 30 years if male or age > 40 years if female

35. are borderline abnormal

	(a)	31(a) is true
and	(b)	clinical classification is not normal or unknown
and	(c)	patient is not on digitalis
and	(d	age ≤ 30 years if male or age ≤ 40 years if female

36. are borderline abnormal - possible digitalis effect

	(a)	35(a)(b)(d) are true
and	(b)	patient is on digitalis

37. are consistent with digitalis effect

	(a)	none of the previous statements are true
and	(b)	there are widespread borderline ST and/or T wave changes
and	(c)	patient is on digitalis

38. are probably due to digitalis effect

	(a)	there are borderline ST and/or T wave changes in any group of leads
and	(b)	patient is on digitalis

39. suggest digitalis effect/ ischemia

	(a)	none of the previous statements are true
and	(b)	patient is on digitalis
and	(c)	age ≥ 35 years if female or age ≥ 30 years if male

40. are nonspecific

A.

	(a)	31(a) is true
and	(b)	31(b) is false and clinical classification is not normal
and	(c)	patient is not on digitalis
and	(d)	age > 30 years if male or age > 40 years if female

or B.

	(a)	none of the previous statements is true
and	(b)	there are widespread borderline ST and/or T wave changes
and	(c)	patient is not on digitalis

or C.

	(a)	there are borderline ST and/or T wave changes in any group of leads
and	(b)	patient is not on digitalis

or D.

	(a)	there are borderline ST and/or T wave changes
and	(b)	none of the previous statements is true

41. is nonspecific

	(a)	there is no T wave abnormality or ST segment depression but there is junctional ST depression
and	(b)	there is no myocardial infarction, conduction defect or WPW syndrome result
and	(c)	there is not LVH with ST/T reasons
and	(d	the ST slope > 0° with the ST amplitude ≤ -0.02 mV for any TWO leads (excluding aVR)

10 Miscellaneous

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ATRIAL ABNORMALITIES

If the P wave flag is not set, or rhythm is not sinus, omit this section.

CRITERIA

A.					P duration ≥ 150 ms
B.					P+ amplitude > 0.3 mV in any one of II, III, aVF
C.				i.	P- amplitude in V1 ≤ -0.15 mV
			and	ii.	P terminal duration in V1 ≥ 40 ms
D.		(a)		i.	Age > 30 days
			and	ii.	P+ in V1 > 0.20 mV
					or P+ in V2 > 0.225 mV
	or	(b)		i.	Age ≤ 30 days
			and	ii.	P+ in V1 > 0.25 mV
					or P+ in V2 > 0.25 mV

STATEMENTS

1. Possible right atrial abnormality

	1.	(a)	B is true
or	2.	(a)	D is true
	and	(b)	A is false
	and	(c)	clinical classification is not respiratory disease

2. Consider left atrial abnormality

	(a)	A is true
and	(b)	D is false

3. Possible right atrial abnormality consistent with pulmonary disease

	(a)	D is true
and	(b)	A is false
and	(c)	clinical classification is respiratory disease

4. Possible left atrial abnormality

	(a)	C is true
and	(b)	D is not true

5. Possible biatrial enlargement

	(a)	D is true
and	(b)	A or C is not true

QRS AXIS DEVIATION

The section on frontal plane abnormalities is omitted if Leads I, II, III are not available. The following age dependent equation is used to calculate the upper limit of normal QRS axis for patients with an age ≤ 6 months.

$$LIM = [230 - 0.66*age\ (days)]$$

The maximum value of LIM is set at 110° for patients over the age of 6 months.

STATEMENTS

1. Indeterminate axis

(a) the (algebraic) sum of the amplitudes of Q,R and S < 0.15mV in Leads I, II and III.

If the above statement is true, omit the remainder of this section.

2. Leftward axis

(a) age > 30 years
and i. -30° < overall QRS axis ≤ -20°
or (b) 15 ≤ age ≤ 30 years
and i. QRS axis < (15 - age (years)) * 2 + 10

3. Left axis deviation

(a) age > 30 years
and i. -120° < overall QRS axis ≤ -30°
and ii. QRS area in aVF < 0
or (b) 15 ≤ age ≤ 30 years
and i. QRS axis < (15 - age (years)) * 2
or (c) age < 15 years
and i. -120° ≤ overall QRS axis ≤ -45°
and ii. QRS area in aVF < 0

4. QRS axis leftward for age

(a) age < 7 days
and i. -120° < overall QRS axis < 75°
and ii. (QRS axis < 0° and QRS area aVF > 0) is false
or (b) 7 days ≤ age ≤ 182 days
and i. -120° < QRS axis < 78° - (78*Agedys)/182
or (c) 183 days ≤ age < 15 years
and i. -120° < QRS axis < 0°

5. Rightward axis

(a) age ≥ 182 days
and i. 90° < overall QRS axis < LIM

6. Right axis deviation

(a) LIM ≤ overall QRS axis < max (LIM + 20, 180°)
(usually 110°→180° for age > 6 months)

7. Left anterior fascicular block

If all the following criteria are met, this statement replaces Nos. 2, 3, and 4.

(a) **LBBB** or **RBBB WITH LEFT ANTERIOR FASCICULAR BLOCK** are not present
and (b) QRS duration < 120ms
and (c) |S| > R amplitude in Lead II
and (d) in aVL, Q ≤ 0.02mV, with |R/Q| > 3
and (e) i. intrinsicoid deflection in aVL exceeds 42 ms
or ii. 6/8 spatial velocity < 50mV/sec and S < -0.1mV in V5
and (f) -120° < QRS axis ≤ -45°

8. Possible left anterior fascicular block

(a) 7(a) to 7(e) are true
and (b) -45° < QRS axis < -30°

9. Possible left posterior fascicular block

If all the following criteria are met, this statement replaces Nos. 5 and 6.

(a) RVH is not present
and (b) i. 90° < QRS axis < 180° and age ≥ 30
or ii. 105° < QRS axis < 180° and age < 30
and (c) QRS duration < 120 ms
and (d) R or R' in lead II > 0.8 mV
and (e) R or R' in lead III > 1 mV
and (f) Q ≤ -0.02mV in leads II and III

10. Severe right axis deviation

(a) max(LIM + 20, 180°) < overall QRS axis < 240°
(normally 180°→240° for age > 6 months)

LOW QRS VOLTAGES

STATEMENTS

1. Low QRS voltages in limb leads

(a) peak to peak voltage < 0.5 mV for all of Leads I, II and III

2. Low QRS voltages in precordial leads

(a) i. peak to peak voltage < 1 mV for all of leads V1, V2, V3, V4, V5 and V6

or ii. peak to peak < 0.5 mV for all of V4, V5 and V6

3. Generalized low QRS voltages

(a) both 1 and 2 are true

TALL T WAVES

STATEMENTS

1. Tall T waves - consider acute ischemia or hyperkalemia

(a) T+ amplitude > an age and gender dependent limit in all leads V3 to V5, as detailed in the table below

and (b) Left Bundle Branch Block is not present

Table of age and gender dependent limits:

	Age < 30	Age ≥ 30
Female	0.9 mV	0.75 mV
Male	1.6 mV	1.2 mV

SUMMARY CODES

There are seven summary codes available. Each diagnostic statement and dominant or supplementary rhythm statement is assigned a summary code and the highest code present in an interpretation is then printed. The various codes in ascending order are as follows:

1. **Normal ECG**
2. **Normal ECG except for rate**
3. **Normal ECG except for rhythm**
4. **Normal ECG based on available leads**
5. **Borderline ECG**
6. **Abnormal ECG**
7. **Technical error**

Example

The following is an example of how a summary code might be used:

Sinus tachycardia

Normal ECG except for rate

11 Rhythm Statements

Contents

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- DOMINANT RHYTHM STATEMENTS 11-3
- SUPPLEMENTARY RHYTHM STATEMENTS 11-5

The rhythm section of the program will always select one statement (only) from the list of dominant rhythms and if appropriate will select up to three additional statements from the list of supplementary statements.

Note: A period (.) appears at the end of the rhythm section if the age and/or gender were not entered prior to ECG analysis.

*** SIGNIFICANT ARRHYTHMIA ***

The statement, *** **SIGNIFICANT ARRHYTHMIA** ***, will be output if any of the following statements appear on the report:

- **Supraventricular tachycardia**
- **Probable supraventricular tachycardia**
- **Probable ventricular tachycardia**
- **Consider ventricular flutter/fibrillation**
- **Accelerated idioventricular rhythm**
- **Possible idioventricular rhythm**
- **Wide QRS tachycardia**
- **Possible ventricular escape rhythm**
- **Wide QRS tachycardia**
- **A-V dissociation**
- **with paroxysmal idioventricular rhythm**
- **with multifocal interpolated PVCs**
- **with frequent multifocal PVCs**
- **with non-sustained ventricular tachycardia**
- **with 2nd degree A-V block, Mobitz I (Wenckebach)**
- **with 2nd degree A-V block, Mobitz II**
- **with complete A-V block**

The presence of either of the statements

*** **EXTREME TACHYCARDIA** ***

*** **EXTREME BRADYCARDIA** ***

on the report will inhibit the output of the *** SIGNIFICANT ARRHYTHMIA *** statement.

DOMINANT RHYTHM STATEMENTS

1. Sinus rhythm
2. Sinus tachycardia
3. Sinus bradycardia
4. Sinus arrhythmia
5. Sinus tachycardia with sinus arrhythmia
6. Sinus bradycardia with sinus arrhythmia
7. Atrial tachycardia
8. Atrial flutter
9. Atrial fibrillation
10. Junctional rhythm
11. Accelerated junctional rhythm
12. Junctional bradycardia
13. Atrial pacing
14. Ventricular pacing
15. A-V sequential pacemaker
16. Possible ectopic atrial rhythm
17. Possible ectopic atrial tachycardia
18. Possible ectopic atrial bradycardia
19. Irregular ectopic atrial rhythm
20. Irregular ectopic atrial tachycardia
21. Irregular ectopic atrial bradycardia
22. Probable atrial tachycardia
23. Probable sinus tachycardia
24. Probable supraventricular tachycardia
25. Marked sinus bradycardia
26. Probable atrial flutter
27. Probable atrial fibrillation

28. **Probable junctional rhythm**
29. **Probable accelerated junctional rhythm**
30. **Probable ventricular tachycardia**
31. **Wide QRS tachycardia**
32. **Accelerated idioventricular rhythm**
33. **Possible idioventricular rhythm**
34. **Possible atrial flutter**
35. **Possible junctional rhythm**
36. **Possible accelerated junctional rhythm**
37. **Possible junctional bradycardia**
38. **A-V dissociation**
39. **Undetermined rhythm**
40. **Regular supraventricular rhythm**
41. **Irregular supraventricular rhythm**

SUPPLEMENTARY RHYTHM STATEMENTS

The following statements are linked to dominant rhythm statements.

1. **with frequent PVCs**
2. **with multifocal PVCs**
3. **with frequent multifocal PVCs**
4. **with interpolated PVC(s)**
5. **with multifocal interpolated PVCs**
6. **with PVC(s)**
7. **with PAC(s)**
8. **with frequent PACs**
9. **with aberrantly conducted supraventricular complexes**
10. **with 1st degree A-V block**
11. **with borderline 1st degree A-V block**
12. **with 2nd degree A-V block, Mobitz I (Wenckebach)**
13. **with 2nd degree A-V block, Mobitz II**
14. **with 2:1 A-V block**
15. **with 3:1 A-V block**
16. **with 4:1 A-V block**
17. **with high degree A-V block**
18. **with varying 2nd degree A-V block**
19. **with complete A-V block**
20. **with 2nd degree (Mobitz II) SA Block**
21. **with bigeminal PACs**
22. **with bigeminal PVCs**
23. **Demand atrial pacing**
24. **Demand pacing**
25. **with fusion complexes**
26. **with non-sustained ventricular tachycardia**

27. **with intermittent conduction defect**
28. **with paroxysmal idioventricular rhythm**
29. **with undetermined ectopic complexes**
30. **with undetermined irregularity**

The following four statements are added to other rhythm statements where appropriate.

31. **or aberrant ventricular conduction**
32. **with rapid ventricular response**
33. **with uncontrolled ventricular response**
34. **with slow ventricular response**

12 Program Accuracy

Contents

- Databases 12-2
- Interpretation accuracy 12-6
- Measurement accuracy 12-21

Databases

Several databases have been used to evaluate the accuracy of the program. Some are external such as the CSE database and others have been constructed in the University of Glasgow. Each is described in detail.

CSE (Common Standards for Quantitative Electrocardiography) database

Table 12-1 on page 12-8 - Table 12-3 on page 12-10, which follow this section, provide the results of analyzing the 1220 ECGs in the Common Standards for Quantitative Electrocardiography (CSE) database using Version 25 of the Glasgow Program. The analysis was undertaken in early November 2002. The following is a brief explanation of the study and the outputs.

The CSE database [17] was constructed by acquiring ECGs from 1220 individuals (831 men, 389 women, mean age 52 ± 13 years). The ECGs were acquired in five different European centres using a variety of equipment but signals were sampled at 500 samples/sec and all leads were recorded simultaneously. Individual centers in the study processed the ECGs in their own local laboratory and submitted the interpretations, mapped to an agreed scheme, e.g. LVH was 21A, to a central lab in Leuven, Belgium where data on sensitivity, etc. were calculated. In other words, the true classification of the cases was known only to the core lab, and in practical terms this meant that the classifications were effectively stored inside software used to determine the accuracy of individual programs. This is still the case today, but following the untimely death of Professor Jos Willems who directed the lab in Leuven, the responsibility for maintaining the secrecy of the classifications and for providing further assessments of software accuracy has transferred to the lab of Professor Paul Rubel, based in Lyon, France.

The composition of the study population included 286 individuals who were apparently healthy and 96 patients referred for cardiological investigation but found to have no cardiac abnormality, who together made up a group of 382 controls. The remaining 838 subjects had known clinical conditions, e.g. myocardial infarction, valvular heart disease. Patients were therefore classified as having ventricular hypertrophy, myocardial infarction or "no structural abnormality" on the basis of clinical information. This could have included echocardiographic data, cardiac enzyme data and in some cases, a knowledge of intra cardiac pressures determined at cardiac catheterisation. Three cardiologists from different European countries reviewed the clinical data and agreed on the classification. The first set of results is based on this information. Thus, a sensitivity of 54.6% for left ventricular hypertrophy (LVH) is with respect to a clinical classification that is expected to accompany such an abnormality.

It is also important to understand that ST-T abnormalities in isolation were mapped to NORMAL (or more strictly NO STRUCTURAL ABNORMALITY). Thus if a patient had an inferior myocardial infarction, and a program reported ST-T abnormalities

suggestive of myocardial ischemia, the corresponding ECG would be regarded as a false negative and placed in the normal/inferior MI box, i.e. in the computer report of normal column in the row entry for inferior MI, where the percentage is 22.3%.

Some patients had multiple abnormalities such as left ventricular hypertrophy and inferior myocardial infarction. A complicated scoring system allowed for such combinations to be considered and some of the outputs therefore state that there was "additional mixing" in the CSE test centre. In general terms, this mixing gave credit for both abnormalities in such a patient being reported by a program. Thus, the use of mixing leads to an enhanced result or total accuracy.

Separately from this form of classification, which was not always acceptable to members of the CSE Working Group, was another classification produced by a set of 8 cardiologists. In turn, the accuracy of the cardiologists was assessed against the clinical data but, on the other hand, their interpretations were combined to produce a so-called "cardiologist interpretation" or "referee consensus" with respect to which programs were also evaluated. There was not much in the way of detail from this aspect of the CSE study presented in the original paper [17] in 1991 although outcomes were lodged separately with the publisher.

As might be expected, a completely different set of results is obtained when the cardiologist is used as the gold standard. Consider the following example by way of explanation.

A patient may well have LVH by echo but a normal ECG. With respect to the clinical database, a program reporting a normal ECG in this patient would be regarded as providing a false negative result. On the other hand, the cardiologists' combined opinion in this case would also be a normal ECG, similar to the computer. In this case, the program would be regarded as providing the correct interpretation. Thus, the same ECG may be correct with respect to one gold standard and incorrect with respect to another.

In general terms, it can be seen that the program has a much higher agreement with cardiologists than with the clinical data. Part of the answer lies in the previous paragraph, e.g. 54.6% correct diagnoses of LVH vs. the clinical data and 69.9 % vs. the cardiologists. Note also that in the group of 382 controls, the Glasgow program agreed in 98.6% of cases with the cardiologists.

This database remains the only truly independent ECG database with "secret" classifications for individual cases.

Glasgow validation ECG database

Within the Glasgow lab, a number of databases have been assembled. The validation ECG database was selected to provide a wide range of normal and abnormal ECGs, including arrhythmias, conduction defects, etc., that could be used to test the Glasgow program. It was constructed mainly from ECGs recorded from hospitalized patients or individuals visiting outpatient clinics. The ECGs are not clinically classified but 1000 were selected as a representative sample of a hospital population. Subsequent scrutiny of this dataset revealed that there were 3 duplicated ECGs. These have been removed from this set to maintain the integrity of the database. The database is often used as a test set to ensure that a copy of the program compiled in a different environment will produce the same results as in its native development system. There are 504 males (mean age 62 ± 22 years) and 493 females (mean age 68 ± 19 years) in the database with an age range of 3 days to 95 years. There were 74 subjects with an age of 16 years or under or aged 17 to 18 years where the leads had been placed as for a pediatric recording. The racial distribution of this database is unknown but given that it is used for assessing arrhythmias and Type B statements, this is of no relevance.

Glasgow adult normal database

The normal ECG database was composed of ECGs recorded from 1501 apparently healthy individuals who were each examined by a physician and who had no evidence of heart disease or any other condition such as diabetes which might be expected to lead to cardiovascular abnormalities. Careful scrutiny of this dataset revealed that there were 5 duplicated ECGs. These have been removed from this set to maintain the integrity of the database. This database has been used extensively in the determination of normal limits of ECGs such as those relating to the QT interval [7]. It contains ECGs from 859 males and 637 females with an age range of 18 to 82 years. This cohort was recruited from local government workers in Glasgow plus students from the University and was essentially 100% Caucasian.

Glasgow pediatric ECG database

This database of 840 ECGs was recorded from neonates, infants and children referred or admitted to hospital for investigation of various problems. There were 436 males (mean age 5.6 ± 5.1 years) and 401 females (mean age 5.6 ± 5.2 years) with a combined age range of 1 day to 18 years. The subject's gender was not recorded in three cases. Race was also not recorded but the population can be assumed to be 100% Caucasian, including children whose parents have immigrated into Scotland from South Asia. The gold standard was the overeader's opinion. Results for RVH and LVH used the combined interpretation of two pediatric cardiologists who were provided with clinical information on a subset of 554 children whose ECGs were being reviewed. The remaining ECGs were reported without knowledge of the clinical history. Results using this database have been published [18], [19].

Pacemaker ECG database

The accuracy of statements relating to artificial implanted pacemaker rhythm is entirely dependent on the detection of the pacemaker stimuli. Age, gender and racial distribution are of no relevance.

Database of additional cases of atrial fibrillation

In order to supplement the number of cases of atrial fibrillation, an additional 72 cases were added to the database ECGs from which rhythm analysis was assessed. There were 48 males (mean age 66.3 ± 15.8 years) and 24 females (mean age 74.3 ± 8.4 years).

Measurement databases per IEC 60601-2-51

Standard databases for automated measurements on ECGs include (1) 16 CTS calibration and analytical ECGs, (2) 100 CSE biological measurement ECGs, and (3) subset of 10 CSE ECGs for testing noise stability.

Our program has been evaluated digitally in the electrocardiograph using all 3 databases.

Table 12-12 on page 12-21 discloses measurement stability in the presence of various types of added noise.

Interpretation accuracy

ECG classification

A task force of the American College of Cardiology established a classification system for ECG abnormalities on the basis of the types of statements that could be made. These are as follows:

Type A: An ECG abnormality which can be confirmed by non electrocardiographic means, e.g ventricular hypertrophy that can be confirmed by echocardiography, or recent myocardial infarction confirmed by a rise in biomarkers;

Type B. An ECG abnormality basically detected by the ECG itself, e.g arrhythmias or conduction abnormalities such as bundle branch block;

Type C. An ECG abnormality that is essentially descriptive, e.g. axis deviation, moderate ST elevation etc.

Definitions

TRUE POSITIVE (TP)= A correct report of an abnormality being present

TRUE NEGATIVE (TN) = A correct report of an abnormality being absent

FALSE POSITIVE (FP)= An incorrect report of an abnormality being present

FALSE NEGATIVE (FN) = An incorrect report of an abnormality being absent

SENSITIVITY (SENS) = TP / (TP + FN)

SPECIFICITY (SPEC) = TN / (TN + FP)

POSITIVE PREDICTIVE VALUE (PPV) = TP / (TP + FP)

NEGATIVE PREDICTIVE VALUE (NPV) = TN / (TN + FN)

$$\text{PREVALENCE} = \frac{\text{Number of occurrences of an abnormality}}{\text{Total number of cases in the database}}$$

TOTAL ACCURACY = (Total number of cases correctly classified) /1220

CSE ABBREVIATIONS

NORM = Normal

LVH = Left ventricular hypertrophy

RVH = Right ventricular hypertrophy

BVH = Right and left ventricular hypertrophy

MI = Myocardial infarction

AMI = Anterior myocardial infarction

IMI = Inferior myocardial infarction

MIX = Anterior and inferior myocardial infarction

VH+MI = Ventricular hypertrophy and myocardial infarction

OTHER = Cardiologist defined abnormality excluding above definitions

Results

Note: Brief format analysis statements appear throughout the results in the tables and rhythm statement lists for presentation clarity.

Table 12-1: Results from an analysis of the CSE database in November 2002. In this case, the gold standard ("truth") was derived from the clinical data.

TYPE A STATEMENTS[a]

DIAGNOSTIC CATEGORY	SENSITIVITY (%)	SPECIFICITY (%)	PPV (%)	NPV (%)	PREVALENCE (ECG Cases)
NORM	97	78[b]	67[b]	99	382/1220
LVH	55	98	85	93	183/1220
RVH	42	100	96	97	55/1220
BVH	48	99	78	98	53/1220
AMI	71	98	88	95	170/1220
IMI	74	98	91	93	273/1220
MIX	69	98	68	98	73/1220

a. The CSE database does not allow a meaningful interpretation of statistics on statements involving "possible" and "probable" qualifiers. They are taken into account in determining the sensitivity, etc. of the various diagnoses as the statement with the highest likelihood, where definite > probable > possible, is given most weight in handling a specific interpretation.

b. Specificity and positive predictive value for 'NORMAL' should be interpreted carefully. A report of 'NORMAL' in a case of 'MYOCARDIAL INFARCTION' or 'hypertrophy' contributes to decreased specificity for 'NORMAL' (even though the ECG may appear 'NORMAL'). In the CSE study, an ECG report stating only 'MYOCARDIAL ISCHEMIA' was mapped to 'NORMAL' even if the true answer was 'INFARCTION', thereby also contributing to decreased specificity for 'NORMAL'.

Table 12-2: Results from an analysis of the CSE database in November 2002. In this case, the gold standard ("truth") was derived from the clinical data. In this table, there is a more detailed breakdown of the reports, e.g. 0.5% of ECGs from individuals regarded as normal were reported by the program as LVH. On the other hand, 30.6% of ECGs from patients with clinical evidence of LVH were reported as normal.

TYPE A STATEMENTS

Truth \ Program	NORM (%)	LVH (%)	RVH (%)	BVH (%)	AMI (%)	IMI (%)	MIX (%)	VH +MI (%)	OTHER (%)	TOTAL (%)	PREV (ECG Cases)
NORM	**97.4**	0.5	0.0	0.0	1.3	0.8	0.0	0.0	0.0	100	382/1220
LVH	30.6	**54.6**	0.0	2.2	4.1	7.1	0.8	0.0	0.5	100	183/1220
RVH	43.6	5.5	**41.8**	3.6	0.0	1.8	1.8	0.0	1.8	100	55/1220
BVH	11.3	0.0	0.0	**47.6**	8.5	1.9	0.0	0.0	30.7	100	53/1220
AMI	14.1	4.1	0.0	0.6	**70.6**	1.8	8.8	0.0	0.0	100	170/1220
IMI	22.3	0.9	0.4	0.0	0.0	**73.8**	2.2	0.0	0.4	100	273/1220
MIX	4.1	4.5	0.0	0.0	0.0	0.0	**68.8**	0.0	22.6	100	73/1220
VH+MI	30.6	0.0	0.0	0.0	0.0	0.0	0.0	**48.4**	21.0	100	31/1220

Table 12-3: Distributions of the CSE November 2002 computer interpretations with respect to the consensus opinion of the 8 cardiologists. Prevalence totals change compared to Tables 12.1 and12.2 because the gold standard has changed.

TYPE A STATEMENTS

Program / Referee	NORM (%)	LVH (%)	RVH (%)	BVH (%)	AMI (%)	IMI (%)	MIX (%)	VH +MI (%)	OTHER (%)	TOTAL (%)	PREV (ECG Cases)
NORM	**92.8**	1.4	0.6	0.5	0.8	2.2	0.1	0.0	1.6	100	503/1220
LVH	19.7	**69.9**	0.0	2.8	1.0	4.8	1.0	0.0	0.7	100	145/1220
RVH	31.7	0.0	**63.3**	0.0	1.7	0.0	3.3	0.0	0.0	100	30/1220
BVH	5.2	5.2	5.2	**72.4**	5.2	0.0	0.0	0.0	6.9	100	29/1220
AMI	7.9	2.5	0.0	1.3	**78.9**	0.9	8.5	0.0	0.0	100	159/1220
IMI	11.2	1.1	0.2	0.2	0.0	**86.0**	1.3	0.0	0.0	100	228/1220
MIX	6.3	0.7	0.0	0.0	2.8	6.9	**76.4**	0.0	6.9	100	72/1220
VH+MI	22.7	2.3	0.0	0.0	0.0	6.8	0.0	**61.4**	6.8	100	22/1220
OTHER	4.7	3.1	0.0	7.8	6.3	0.0	3.1	4.7	**70.3**	100	32/1220
TOTAL	45.5	9.7	2.0	2.7	11.2	18.2	6.2	1.2	3.3	**100**	**1220**

Table 12-4: Results on type B statements. Data were obtained from the Glasgow validation ECG database from which 74 children's ECGs were removed in order to provide results on adults only. In addition, 31 WPW examples were obtained from a group of 31 patients being investigated by electrophysiological testing. There were therefore 923 +31 (954) ECGs available for assessment of type B statements in adults.

TYPE B STATEMENTS - CONDUCTION DEFECTS					
CONTOUR CATEGORIES	**SENS (%)**	**SPEC (%)**	**PPV (%)**	**NPV (%)**	**PREVALENCE (ECG Cases)**
RBBB	100.00	99.57	85.71	100.00	24/954
LBBB	100.00	99.89	94.74	100.00	18/954
rSr′ (V1) - probable normal variant	100.00	100.00	100.00	100.00	16/954
IVCD	95.65	98.93	68.75	99.89	23/954
WPW pattern	75.76	100.00	100.00	99.14	33/954
LAFB	100.00	100.00	100.00	100.00	34/954

Where a diagnostic abnormality occurred in the database with a frequency < 10, no statistics are given as they are likely to be unreliable. The following Type B abnormalities fall into that category:

- RBBB with LAFB
- Incomplete RBBB
- Incomplete LBBB

There were no examples of the following Type B abnormalities:

- Extensive IVCD
- LPFB

Where:

RBBB = Right bundle branch block

LBBB = Left bundle branch block

LAFB = Left anterior fascicular block

LPFB = Left posterior fascicular block

IVCD = Intra ventricular conduction defect

WPW = Wolf Parkinson White

Table 12-5: Results of rhythm interpretations. Several databases were combined to provide a database of reasonable size for assessing the accuracy of the rhythm interpretation section of the program. The first was the Glasgow validation ECG database. A second database of 1496ECGs from apparently healthy adults was also incorporated to increase the number of sinus based rhythms. These ECGs were supplemented by 72 cases of atrial fibrillation that were included to augment the number of cases of this arrhythmia.

TYPE B STATEMENTS - RHYTHM

Note: "True" rhythm: All of the rhythms were reviewed and classified by a cardiology professor with over 30 years experience in reading and teaching electrocardiograms and has been published widely on ECG matters. None of the rhythms in the database presented any difficulty in interpretation. It should be noted that cardiac rhythm is less susceptible to error in interpretation than morphological analysis of the basic 12 leads, where there is considerable observer variation often necessitating a consensus opinion.

DOMINANT RHYTHM STATEMENT	SENS (%)	SPEC (%)	PPV (%)	NPV (%)	PREV (ECG Cases)
Sinus rhythm	99.71	98.15	99.15	99.38	1754/2565
Sinus bradycardia	99.35	99.60	97.14	99.91	308/2565
Atrial fibrillation	90.28	99.92	98.48	99.43	144/2565
Sinus arrhythmia	91.59	100.00	100.00	99.64	107/2565
Sinus tachycardia	98.75	99.72	91.86	99.96	80/2565
Sinus bradycardia with sinus arrhythmia	82.93	100.00	100.00	99.72	41/2565
Atrial flutter	92.50	99.96	97.37	99.88	40/2565
Possible atrial flutter	100.00	99.80	86.84	100.00	33/2565
Possible ectopic atrial rhythm	88.46	99.92	92.00	99.88	26/2565
Possible ectopic atrial bradycardia	85.71	99.96	92.31	99.92	14/2565

Where an arrhythmia occurred in the database with a frequency < 10/2565, no statistics are given as they are likely to be unreliable. The following arrhythmias fall into that category:

- A-V dissociation
- Probable atrial fibrillation
- Probable accelerated junctional rhythm
- Probable supraventricular tachycardia
- Probable sinus tachycardia
- Sinus tachycardia with sinus arrhythmia
- Irregular ectopic atrial bradycardia
- Probable atrial tachycardia
- Marked sinus bradycardia
- Regular supraventricular rhythm

The database of ECGs did not contain any examples of the following arrhythmias:

- Possible accelerated junctional rhythm
- Supraventricular tachycardia
- Irregular ectopic atrial rhythm/tachycardia
- Atrial tachycardia
- (Probable/Possible) junctional rhythm
- (Possible) junctional bradycardia
- Possible ectopic atrial tachycardia
- Wide QRS tachycardia
- Accelerated idioventricular rhythm
- Possible idioventricular rhythm
- Probable atrial flutter
- Undetermined rhythm
- Irregular supraventricular rhythm
- Probable ventricular tachycardia
- (Accelerated) junctional rhythm

Table 12-6: Results for supplementary rhythm statements using the same database as for Table 12-5

SUPPLEMENTARY STATEMENT	SENS (%)	SPEC (%)	PPV (%)	NPV (%)	PREV (ECG Cases)
~ with rapid ventricular response	98.57	99.96	98.57	99.96	70/2565
~ with PVC(s)	95.08	99.84	93.55	99.88	61/2565
~ with PAC(s)	100.00	98.97	65.33	100.00	49/2565
~ with borderline 1st degree A-V block	94.23	98.89	63.64	99.88	52/2565
~ with 1st degree A-V block	92.11	99.76	85.37	99.88	38/2565
~ or aberrant ventricular conduction	94.12	99.92	88.89	99.96	17/2565
~ with slow ventricular response	100.00	99.92	86.67	100.00	13/2565

Where a supplementary rhythm statement occurred in the database with a frequency < 10/2565, no statistics are given as they are likely to be unreliable. The following statements fall into that category:

- ~ with frequent (multifocal) PVCs
- ~ with uncontrolled ventricular response
- ~ with 2:1/ 3:1 / 4:1 A-V block
- ~ with aberrantly conducted supraventricular complexes
- ~ with frequent PACs
- ~ with multifocal PVCs
- ~ with undetermined irregularity
- ~ with paroxysmal idioventricular rhythm
- ~ with complete A-V block
- ~ with bigeminal PVCs

The database of ECGs did not contain any examples of the following supplementary rhythm statements:

- ~ with (multifocal) interpolated PVC(s)
- ~ with 2nd degree A-V block, Mobitz I (Wenckebach)
- ~ with 2nd degree A-V block, Mobitz II
- ~ with varying 2nd degree A-V block
- ~ with high degree A-V block
- ~ with bigeminal PACs
- ~ with 2nd degree (Mobitz I) SA block
- ~ with 2nd degree (Mobitz II) SA block

- ~ with non sustained VT
- ~ with intermittent conduction defect
- ~ with fusion complexes
- ~ with unclassified aberrant complexes
- ~ with undetermined ectopic complexes

Table 12-7: Data derived from 155 cases of paced ECGs.

Pacing statement	SENS (%)	SPEC (%)	PPV (%)	NPV (%)	Prevalence (ECG Cases)
Atrial pacing	8.33	97.90	25.00	92.72	12/155
Demand atrial pacing	100.00	99.35	50.00	100.00	1/155
Ventricular pacing	73.17	90.41	89.55	75.00	82/155
A-V sequential pacemaker	36.36	100.00	100.00	85.31	33/155
Demand pacing	81.48	85.94	55.00	95.65	27/155

Table 12-8: Type C statements in adults derived from the Glasgow validation ECG database less the 74 children's ECGs.

CONTOUR CATEGORIES	SENS (%)	SPEC (%)	PPV (%)	NPV (%)	PREV (ECG Cases)
Left axis deviation	100.00	100.00	100.00	100.00	70/923
Leftward axis	100.00	100.00	100.00	100.00	64/923
Right axis deviation	100.00	100.00	100.00	100.00	12/923
Rightward axis	100.00	100.00	100.00	100.00	12/923
Nonspecific ST + T changes	95.45	98.07	93.10	98.75	198/923
rSr' (V1) – probable normal variant	100.00	100.00	100.00	100.00	16/923
Poor R wave progression	100.00	100.00	100.00	100.00	37/923

Where a diagnostic abnormality occurred in the database with a frequency < 10, no statistics are given as they are likely to be unreliable. The following Type C abnormalities fall into that category:

- Severe right axis deviation
- Indeterminate axis
- ST elevation (either non-specific or due to early repolarisation or pericarditis)
- Low QRS voltage
- Tall T waves

Table 12-9: ECGs for this table were taken from the Glasgow pediatric ECG database. (See description of this database for an explanation of prevalences)

TYPE A STATEMENTS IN CHILDREN					
CONTOUR CATEGORIES	**SENS (%)**	**SPEC (%)**	**POSITIVE PRED. VALUE (%)**	**NEGATIVE PRED. VALUE (%)**	**PREV (ECG Cases)**
Normal	89.53	98.41	98.09	91.14	401/840
RVH	50.79	95.32	58.18	93.79	63/554
LVH	33.33	95.97	34.38	95.79	33/554

When calculating the statistics, statements reporting "possible" as well as definite ventricular hypertrophy were taken into account when determining the sensitivity etc. of the appropriate diagnosis.

Gold standard data was not available for the following Type A abnormalities:

- BVH
- Ventricular Hypertrophy with secondary repolarisation abnormality

Statistics for the following abnormalities are not available as they could not be confirmed by non-electrocardiographic means.

- Atrial abnormalities
- Abnormal ventricular conduction pathways (Q waves)
- Borderline high QRS voltage - probable normal variant

Where:

RVH = Right ventricular hypertrophy

LVH = Left ventricular hypertrophy

BVH = Biventricular hypertrophy

Table 12-10: Results on Type B abnormalities in the Glasgow pediatric ECG database.

TYPE B ABNORMALITIES IN CHILDREN					
CONTOUR CATEGORIES	**SENS (%)**	**SPEC (%)**	**POSITIVE PRED. VALUE (%)**	**NEGATIVE PRED. VALUE (%)**	**PREV (ECG Cases)**
RBBB	89.09	99.11	87.50	99.23	55/840
IVCD	86.36	99.76	90.48	99.63	22/840

Where a diagnostic abnormality occurred in the database with a frequency < 10, no statistics are given as they are likely to be unreliable. The following Type B abnormalities in children fall into that category:

- WPW
- LBBB
- Incomplete RBBB
- Incomplete LBBB
- rSr' (V1) normal variant

Where:

RBBB = Right bundle branch block

LBBB = Left bundle branch block

IVCD = Intra ventricular conduction defect

WPW = Wolf Parkinson White

Table 12-11: Results on Type C abnormalities in 840 ECGs in the Glasgow pediatric ECG database.

TYPE C ABNORMALITIES IN CHILDREN					
CONTOUR CATEGORIES	**SENS (%)**	**SPEC (%)**	**POSITIVE PRED. VALUE (%)**	**NEGATIVE PRED. VALUE(%)**	**PREV (ECG Cases)**
Non-specific ST-T changes	100.00	99.58	97.62	100.00	123/840
ST elevation	94.87	100.00	100.00	99.75	39/840
Rightward axis	100.00	100.00	100.00	100.00	72/840
Right axis deviation	100.00	100.00	100.00	100.00	43/840
Severe right axis deviation	100.00	100.00	100.00	100.00	13/840
QRS axis leftward for age	100.00	99.87	97.73	100.00	43/840
Left axis deviation	100.00	99.88	96.67	100.00	29/840

Where a diagnostic abnormality occurred in the database with a frequency < 10, no statistics are given as they are likely to be unreliable. The following Type C abnormalities in children fall into that category:

- Leftward axis
- Indeterminate axis

Measurement accuracy

All dimensions in ms

Table 12-12: Disclosed changes of measurements caused by noise with acceptable tolerances from digital analysis in the electrocardiograph of the 10 CSE ECGs for testing noise stability

		Disclosed differences			
		Mean		Standard Deviation	
Global measurement	**Type of added NOISE**	**Measured**	**Acceptable Tolerance**	**Measured**	**Acceptable Tolerance**
P-duration	High frequency	-0.500	± 10	1.414	± 8
P-duration	Line frequency	0.250	± 10	0.707	± 8
P-duration	Base-line	-0.500	± 10	1.414	± 8
QRS-duration	High frequency	1.750	± 6	3.454	± 5
QRS-duration	Line frequency	2.000	± 6	2.619	± 5
QRS-duration	Base-line	-0.250	± 6	1.669	± 5
QT-interval	High frequency	1.000	± 12	1.069	± 10
QT-interval	Line frequency	0.000	± 12	1.069	± 10
QT-interval	Base-line	-0.250	± 12	1.282	± 10

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