12-Lead ECG Interpretive Program

Physician's Guide

Brief Format Statements

Revision History

Contents of this manual are subject to change without prior notice.

The version information of this manual is as follows:

- Revision number: 5.0
- Release time: 2017-03
- Glasgow algorithm version: 28.4.1

FOR YOUR NOTES

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FOR YOUR NOTES

1 Introduction

3.1.18.1

The Glasgow algorithm, one of the top resting ECG analysis programs which have been under continuous enhancement for over 40 years, has been adopted in Mindray products. The Glasgow algorithm was the first algorithm to include age, gender, and race specific criteria. Now with age and gender based criteria for STEMI, the program performance is superior to the use of the original ESC/ACC criteria. With "Critical Value" warnings incorporated, the program is well suited to the pre-hospital setting.

1.1 History

The University of Glasgow has a long history in being involved in the development of software for interpretation of electrocardiograms. In particular, what is now called the University's ECG core lab, based at Glasgow Royal Infirmary (GRI), introduced what was thought to be the world's first mini computer based system for routine hospital reporting of electrocardiograms in the early 1970s. At that time, use was made of the 3 orthogonal lead ECG which did not prove acceptable to physicians who were more accustomed to the use of the 12-lead ECG. As a result, the Glasgow team commenced the development of completely updated approach to analysing the 12-lead electrocardiogram.

In the 1980s, it was not common for all 12 leads to be recorded simultaneously but the Glasgow development did indeed incorporate this technique and so all wave recognition and interpretation methods were based around this approach.

Given the availability of the new techniques, a database of ECGs from apparently healthy individuals was established from which normal limits of the 12-lead ECG were derived using the newer processing methods. Not only was an adult database collected but a similar database from neonates, infants and children was gathered locally. These databases gave the Glasgow team a unique building block on which to develop diagnostic software.

Also in the 1980s, the Glasgow team were able to acquire ECGs from Taiwan and hence assess whether there were any differences in ECG appearances due to race. Since then, other databases have been acquired much more recently from Nigeria (2010) and India (2011). In short, the development of the Glasgow algorithm continues at the present time.

There have been many publications that have arisen from the work of the Glasgow team. These have related to the effects of age, gender and race on the ECG while others have dealt with clinical problems such as the diagnosis of acute ST elevation myocardial infarction. The use of clinical information and drug therapy, which is optional, can also influence the diagnostic statements produced by the software. Output can be in the form of abbreviated statements or longer diagnostic statements preceded by some reason statements pointing to why a particular diagnostic statement has been printed.

It is often said that medicine is not an exact science and electrocardiography in some ways falls into the same broad classification. Inter and intra observer variation in ECG interpretation are well known and hence, by implication, it has to be accepted that computer assisted reporting of electrocardiograms (C.A.R.E.) is not a perfect science either. It is, however, of enormous benefit to clinicians in the sense that the software allows a check of many hundreds of criteria that can be age, gender and race related and hence, can provide a physician with a guide to interpretation. If an ECG report states that the ECG is within normal limits, then the physician can be assured that numerous criteria for ventricular hypertrophy, for example, have been checked against the age, sex and race of the patient and no abnormally high voltages have been detected. In addition, if an abnormality is suggested, then it will be on the basis of criteria which have been chosen to be highly specific.

If used properly, C.A.R.E. can be of significant assistance to the physician in the routine task of interpreting electrocardiograms.

1.2 ECG Wave Recognition

The methodology for ECG waveform measurement is described in general terms in an earlier publication from the Glasgow Laboratory. Ten seconds of ECG data is input to the software for analysis and all leads require to have been acquired simultaneously [1].

1.2.1 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

1.2.2 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.

1.2.3 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.

1.2.4 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 [2]. In practice, the program forms the straight average, which is compared to individual beats in the same class. If there is a significant difference at any point, then the median beat is used. The modal beat is regarded as being computationally excessive, though it is undoubtedly the best approach to use.

1.2.5 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 [3] (of which one of the Glasgow team was a member), which were published in 1985.

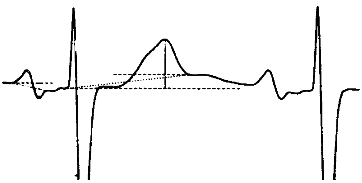

Figure 1 **Varying choice of baselines.**

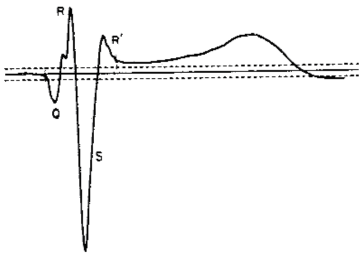

Figure 2 **Baseline at the level of QRS onset as used by the Glasgow program.**

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 Figures 1 - 4).

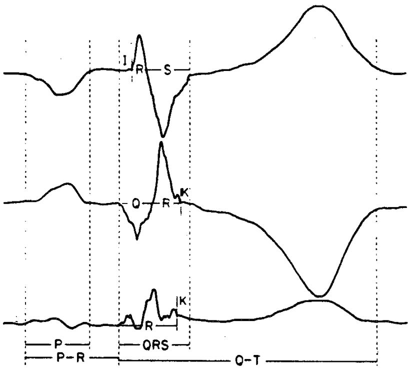

Figure 3 **Illustration of isoelectric segments I and K.**

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 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.

1.2.6 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 [3], 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.

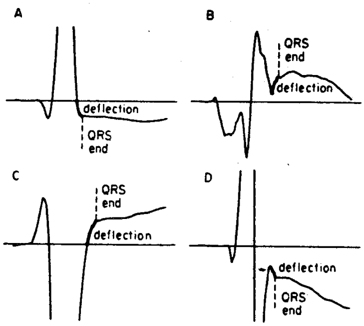

Figure 4 **Definitions for QRS end / ST junction**

3.1.18.2.

1.2.7 ST Segment

The ST segment has several measurements made. Figure 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.

1.2.8 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
3.1.18.2. 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.

1.2.9 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.

1.2.10 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 [4] and a pediatric database derived from 1750 neonates, infants and children, published in part in 1989 [5] and 1998 [6] 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.

3.1.18.4.

1.3 Diagnostic Approach

1.3.1 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 [7].

Only three leads 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 were 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 [8] but ultimately it was found that deterministic methods were equally acceptable. Differentiation of atrial fibrillation with rapid ventricular response from sinus tachycardia with frequent supra VES still remains a difficult problem for automated techniques.

Relatively recently, newer methods for enhancement of reporting atrial flutter were reported by the group [9]. 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.

3.1.18.1

1.3.2 Morphological Interpretation

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

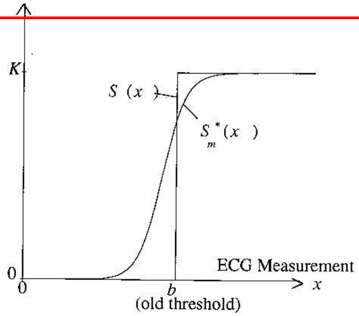

Figure 5 **Replacement of a step function threshold with an exponential function. With the step function, K points are scored when the ECG measurement exceeds the threshold 'b'. With the exponential function, the score varies continuously.**

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 [10] to try to minimise repeat variation in interpretations by avoiding the use of strict thresholds between abnormal and normal (see Figure 5). In short, instead of a step function separating normal from abnormal an exponential or even a linear function between the normal and abnormal threshold value can be used as illustrated. This is 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 [11].

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 [12].

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 [13]. Another example of newer terminology is that of the Brugada pattern of which account has to be taken.

The software makes extensive use of age and sex 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 Chinese individuals, for example.

1.4 Intended Use Application

1.4.1 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 [14] and hence has had wide exposure to recording of electrocardiograms in all commonly required situations.

1.4.2 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 [5, 6]. 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.

1.4.3 Intended Location

The Glasgow Program is intended to be used in 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, sex, and automatically invokes the appropriate criteria and routines such as special logic for acute cardiac ischaemia 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.

1.4.4 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 chapter ***19*** Accuracy of Contour Statements. 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.

2 Preliminary Comments

Advisory statements are included in the diagnostic output. The purpose of these statements is to supply information or give a warning about possible problems with the validity of the data. There are 4 main categories of preliminary comments:

lead related (subdivided into two groups – lead validity and lead reversal/dextrocardia), rhythm related, demographic related and restricted analysis.

2.1 Lead Related

2.1.1 Validity

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

Criteria

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
B			|QRS area| > 500 in Vn-1, Vn, and Vn + 1
C		i.	R amp in V2 + 0.025 < R amp in V1
	and	ii.	T+ amp in V1 > T+ amp in V2 + 0.025
	and	iii.	T+ amp in V3 > T+ amp in V2 + 0.025
	and	iv.	T+ amp in V2 > 0
D		i.	R amp in V1 - R amp in V2 > 0.2 mV
	and	ii.	R amp in V3 - R amp in V2 > 0.2 mV
	and	iii.	|T- amp in V2| > T+ amp in V2
E		i.	T+ amp in V1 > |T- amp in V1| + 0.025
	and	ii.	|T- amp in V2| > |T+ amp in V2| + 0.025
	and	iii.	T+ amp in V3 > |T- amp in V3| + 0.025
F		i.	R amp in V1 > R amp in V2 + 0.4 mV and R' amp in V2 = 0
	and	ii.	R amp in V3 > R amp in V2 + 0.4 mV and R' amp in V2 = 0
G			QRS area in V1 < 0 and QRS area in V2 > 0 and QRS area in V3 < 0 and QRS area in V4 > 0
H		i.	R amp in V2 > R amp in V3 + 200
	or	ii.	|S amp in V1| > |S amp in V2| × 3 and |S amp in V3| > |S amp in V2| × 3
I		i.	Max (R,R') amp in V2 > 2.5× max (R,R') amp in V1 and max (R,R') amp in V4 > 2.5× max (R,R') amp in V3
	and	ii.	Max (R,R') amp V2 > max (R,R') amp V3 + 300
J		i.	There is no Q in V2
	and	ii.	There is not (R' in V1 and V2 but not in V3)
K			There is not a Q in V1 where |Q| > 0.075 mV

Statements

1. **Possible faulty Vn – omitted from analysis**

For leads V2-V5:

	(a)		i.	Peak-peak QRS in any one of V2 to V5 < 0.35mV 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 toV5 < 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: V1, V2 omitted**

	(a)	C or D or E or F is true
and	(b)	K is true

4. **Possible sequence error: V2, V3 omitted**

	(a)		i.	G and H are true
		or	ii.	I is true
and	(b)			J is true

5. **Possible sequence error: Vn, Vn+1 omitted**

For leads V3-V5

	(a)	A and B are true

6. **V1/V2 are at least one interspace too high and have been omitted from the analysis**

	(a)			$\lvert P\text{-}\rvert > 0.05$ mV in leads V1 and V2
and	(b)			0.5 mV > $\lvert R'\rvert > \lvert R\rvert >$ 0.045mV in lead V2
and	(c)		i.	0.5 mV > $\lvert R'\rvert > \lvert R\rvert >$ 0.045mV in lead V1
		or	ii.	$\lvert R'\rvert = 0$ mV in lead V1
and	(d)			$\lvert T\text{-}\rvert > 0.05$ mV in leads V1 and V2

7. **Lead(s) unsuitable for analysis**

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

8. **---Possible measurement error ---**

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

2.2 Measurement Reference

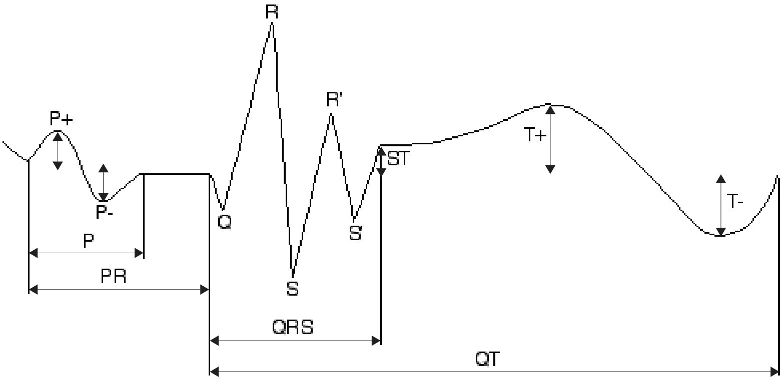

Figure 6 Measurement Reference

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+, P-, 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.

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.**

2.3 P and T Wave Morphologies

Throughout this handbook, 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 follows:

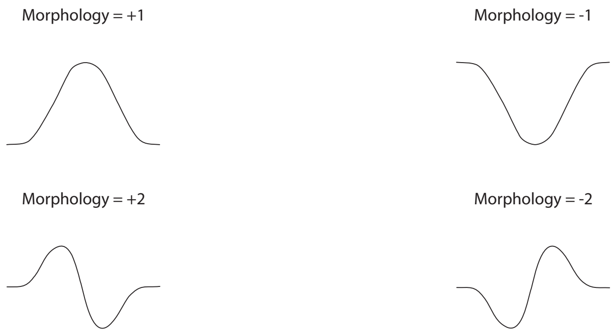

Figure 7 P and T Wave Morphologies

3 Lead Reversal/Dextrocardia

This section of the program aims to detect faulty application of the limb leads and to differentiate this 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			$85° < \text{P axis} \le 180°$ or $-180° \le \text{P axis} < -85°$
C			$85° < \text{QRS axis} \le 180°$, or $-180° \le \text{QRS axis} < -85°$ and (the QRS area in Lead I is negative or [R duration ≥ 40 ms and Q duration ≥ 40 ms])
D			In V6, the peak to peak QRS > 0.5 mV, with the QRS area > 0 and P+ > P- and (R amp in lead I < 0.2mV or there is a Q wave in lead I)
E		i.	$0 \le R(n+1) \le R(n)$ for n = V3, V4, V5 or $R \le 0.1$ 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, $\lvert Q\rvert > R \ge R'$, or $(\lvert S\rvert > R'$, with Q = 0 and $\lvert S\rvert > R+100$
	and	ii.	In V6, S > 0.25 mV or $\lvert R/S\rvert \ge 2$
	and	iii.	ST polarities are opposite in I and V6 as are T wave amplitudes
G			R and R' amplitude < 0.135 mV
H			$\lvert S\rvert$ and $\lvert S'\rvert$ amplitude < 0.05 mV
J			$\lvert Q\rvert < 0.06$ mV
K			$\lvert$QRS area in lead I + QRS area in lead III$\rvert$ < $\lvert$QRS area in lead II$\rvert$ + 50
L			$T+ + \lvert T-\rvert < 0.07$ mV
M			$\lvert$QRS area in lead II - QRS area in lead I$\rvert$ < $\lvert$QRS area in lead III$\rvert$ + 50
N			$90° < \text{T axis} \le 180°$ or $-180° \le \text{T axis} \le -90°$ and P- amplitude in lead I < -0.1 and QRS area in lead I < -500 and T- amplitude in lead I < -0.05
O			P+ amplitude < 0.075
P			$\lvert$QRS area in lead II - QRS area in lead III$\rvert$ < $\lvert$QRS area in lead I$\rvert$ + 50
Q		i.	$-180° < \text{P axis} \le -90°$
R	and	ii.	$-90° \le \text{QRS axis} < -30°$
	and	iii.	$-90° \le \text{T axis} < 0°$
	and	iv.	$\sum \lvert P-\rvert$ over leads I, II, III > 200
	and	v.	Heart rate < 120 bpm

Statements

1. **--- Possible arm lead reversal – hence only aVF, V1 – V6 analyzed ---**

	(a)	A and B and C and (D or F or N) true and E false and age > 180 days
or	(b)	C and F true and (not A) and age > 180 days
or	(c)	A and B and { $\sum T_I \times \sum T_{V6} < 0$ } and age ≤ 180 days where $\sum T_I = T_I + - \lvert T_I - \rvert$ and T+ is the amplitude of the positive component of the T wave and T- is the amplitude of 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. **--- Possible limb lead reversal – hence only V1-V6 analyzed ---**

	(a)		i.	G, H, J, L and O are true for lead II
		and	ii.	K is true
or	(b)		i.	G, H, J, L and O are true for lead III
		and	ii.	M is true
or	(c)		i.	G, H, J, L and O are true for lead I
		and	ii.	P is true

4. **--- Possible arm/leg lead interchange – hence only V1-V6 analyzed ---**

	(a)	Q is true

Rhythm Related

If there is an arrhythmia which results in abnormal ventricular conduction, e.g. VT, the diagnostic report may not be valid. In this case, the following statement will be printed.

1. **If rhythm is confirmed, the following report may not be valid**

Demographic Related

The following statements can be printed in the event of faulty input of clinical data or in the event of missing demographic data. Analysis continues with default values chosen. In addition, there is a statement to indicate if pediatric criteria are being used.

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

3. **--- Interpretation made without knowing patient's gender ---**

4. **--- Interpretation made without knowing patient's age ---**

5. **-- Interpretation made without knowing patient's gender/age --**

6. **--- Interpretation based on pediatric criteria ---**

(a)	The patient is under 18 years of age

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 ---**
4. **--- Technically unsatisfactory tracing ---**

FOR YOUR NOTES

4 Heart Rate

The limits for tachycardia and bradycardia are clearly age related in the neonatal and paediatric 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.

Tachycardia

Age range	Rate in beats / min
Birth - 28 days	163 →180
29 days - 180 days	180
181 days - 17 years	180 → 100
≥ 18 years	100

Bradycardia

Age range	Rate in beats / min
Birth - 28 days	88 → 105
29 days - 365 days	105
1 year (366 days) – 6 years (2191 days)	105 → 60
6 years (2192 days) – 12.5 Years (4600 days)	60 → 50
> 12.5 years (4600 days)	50

NOTE

- **The final limits of 100 and 50 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.

Marked sinus Bradycardia

If the heart rate is less than 40 bpm, then marked sinus bradycardia is reported.

FOR YOUR NOTES

FOR YOUR NOTES

5 Intervals

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

Since QT interval is essentially heart rate related, an age dependent equation has not been utilised. 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.

5.1 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

Statement

1. **Short PR Interval**

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

Age	Limit in ms
0-15 years	75 + 0.006 × age(days)
16 + years	110

2. **with 1st degree A-V block**

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

Age	Limit in 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 table.

Age	Limit in ms
≤ 18 years	143 + 0.0087 × Age (days)
> 18 years	200

NOTE

- **The statements 2 and 3 are determined by the rhythm analysis.**

5.2 QT Interval

If the QRS duration ≥ 120ms, or if the heart rate exceeds 125/minute, omit this section. The criteria in this section use the corrected QT interval denoted QTc. The particular formula for computing QTc is user selectable and can be one of the following:

Hodges[a]

$$QTc = QT + 1.75 \times (HeartRate - 60)$$

Bazett[b]

$$QTc = QT \times \left(\frac{HeartRate}{60}\right)^{\frac{1}{2}}$$

Fridericia[c]

$$QTc = QT \times \left(\frac{HeartRate}{60}\right)^{\frac{1}{3}}$$

Framingham[d]

$$QTc = QT + 154 \times \left(1 - \frac{60}{HeartRate}\right)$$

If there is no facility for the user to select which QTc formula is to be used, the Hodges QTc formula will be used by default[e].

Statements

1. **Borderline prolonged QT interval**

	(a)			Infant < 6 months and 500 ms ≤ QTc < 520 ms
or	(b)			Male and age > 6 months and 460 ms ≤ QTc < 480 ms
or	(c)			Female and
			i.	Age ≥ 50 years and 470 ms ≤ QTc < 490 ms
		or	ii.	6 months < age < 50 years and 460 ms ≤ QTc < 480 ms

[a] Hodges M, Salerno D, Erlien D. Bazett's QT correction reviewed. Evidence that a linear QT correction for heart rate is better.et al., J Am Coll Cardiol.A.C.C. 1983;, 1(2):694.

[b] Bazett HC. An Analysis of the time relations of electrocardiograms., Heart 1920;, 7:353-370.

[c] Fridericia LS. Die systolendauer im electrokardiogramm bei normalen menschen und bei herzkranken., Acta Med Scan 1920;, 53:469-486.

[d] Sagie A, Larson MG, Goldberg RJ, et al. An improved method for adjusting the QT interval for heart rate (the Framingham Heart Study).., Am J Cardiol 1992;70, 79:797-801.

[e] Luo S, Michler K, Johnston P, Macfarlane PW. A 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.

2. **Prolonged QT – consider ischemia, electrolyte imbalance, drug effects**

	(a)			Infant < 6 months and QTc ≥ 520 ms
or	(b)			Male and age > 6 months and QTc ≥ 480 ms
or	(c)			Female and
			i.	Age ≥ 50 years and QTc ≥ 490 ms
		or	ii.	6 months < age < 50 years and QTc ≥ 480 ms

3. **Short QT interval**

	(a)	QTc ≤ 350 ms

FOR YOUR NOTES

6 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 ≥ 40ms
D		(a)		i.	Age > 30 days
			and	ii.	P+ in V1 > 0.20 mV
			or	iii.	P+ in V2 > 0.225 mV
	or	(b)		i.	Age ≤ 30 days
			and	ii.	P+ in V1 > 0.25 mV
			or	iii.	P+ in V2 > 0.25 mV

Statements

1. **Possible right atrial abnormality**

	(a)			B is true
or	(b)		i.	D is true
		and	ii.	A is false
		and	iii.	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 true

7 QRS Axis Deviation

Statements

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

$$LIM = 230 - (0.66 \times \text{age (days)})$$

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

1. Indeterminate axis

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

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

2. Leftward axis

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

3. Left axis deviation

A

				RBBB with left anterior fascicular block is NOT present

and B

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

4. Marked left axis deviation

	(a)			**RBBB with left anterior fascicular block** is NOT present
and	(b)		i.	-120° ≤ overall QRS axis ≤ -45°
		and	ii.	QRS area in aVF < 0

5. **QRS axis leftward for age**

A

				RBBB with left anterior fascicular block is NOT present

and B

	(a)		i.	Age < 7 days
		and	ii.	-120° < overall QRS axis < 75°
		and	iii.	(QRS axis < 0° and QRS area aVF > 0) is not true
or	(b)		i.	7 days ≤ age ≤ 182 days
		and	ii.	-120° < QRS axis < 78° -(78×Age (days))/182
or	(c)		i	183 days ≤ age < 15 years
		and	ii.	-120° < QRS axis < 0°

6. **Rightward axis**

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

7. **Right axis deviation**

	(a)	LIM ≤ overall QRS axis < max (LIM + 10°, 180°) (usually 110° → 120° for age > 6 months)

8. **Marked right axis deviation**

	(a)	LIM +10° ≤ overall QRS axis < max (LIM + 20°, 180°) (usually 120° → 180° for age > 6 months)

9. **Left anterior fascicular block**

(If all the following criteria are met, this statement replaces Nos. 2, 3, 4 and 5)

	(a)	**LBBB** or **RBBB with left anterior fascicular block** or **IVCD** are not present
and	(b)	There is no inferior infarct or extensive infarct
and	(c)	R amplitude > 0 in Lead II
and	(d)	The QRS complexes in leads aVR and aVL each end in an R wave
and	(e)	The peak of the terminal R wave in lead aVR occurs later than the peak of the terminal R wave in lead aVL
and	(f)	-120° < QRS axis ≤ -45°

10. **Possible left anterior fascicular block**

	(a)	9 (a) to 9 (e) are true
and	(b)	-45° < QRS axis < -30°

11. **Possible left posterior fascicular block**

(If all the following criteria are met, this statement replaces Nos. 6, 7 and 8).

	(a)			RVH is not present
and	(b)		i.	90° < QRS axis < 180° and age ≥ 30 years
		or	ii.	105° < QRS axis < 180° and age < 30 years
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 ≤ -0.02 mV in leads II and III

12. **Severe right axis deviation**

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

FOR YOUR NOTES

FOR YOUR NOTES

8 Conduction Defects

The duration criteria for conduction defects are age dependent. As indicated in the Introduction, it is possible to utilise an equation to calculate the upper normal 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 paediatric criteria are derived from an age dependent value intermediate to the two limits.

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

As an example, Criterion 6 A (a) indicates that the R or R' duration in Lead I has to exceed 68ms at birth or 100ms in adulthoood for the criterion to be met, while at age 10, the critical duration would be approximately 85ms.

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.

1. **Left bundle branch block**

A.

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

or B. 1A and 6A are false and from the following criteria either:

(a and b and c and d) is true

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

(a)			QRS duration > LIM1 + 88 ms in any two leads
(b)		i.	In Lead I, V5 or V6: R > LIM1 + 68 ms, with Q > -0.02 mV
	or	ii.	In Lead I, V5 or V6: R' > LIM1 + 68 ms, 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 ms, with corresponding amplitude < -1.0 mV
(e)			The QRS spatial velocity at 4/8 and 5/8 < 100 mV/s
(f)			(R+R') duration summed over I, V5 and V6 > 3 × (LIM1 + 58 ms)

2. **Incomplete LBBB**

	(a)		i.	In V5 or V6, R > LIM1 + 38 ms, with Q > -0.02 mV
		or	ii.	In V5 or V6, R' > LIM1 + 38 ms, 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/s
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
and	(e)			In V1 and V2, R and R' > LIM3 + 15 ms

3. **Right bundle branch block**

A.

	(a)			QRS duration in V5 or V6 > LIM1 + 68 ms, and QRS duration in V1 or V2 > LIM1 + 68 ms
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/s
		or	ii.	The QRS spatial velocity at 6/8 < 40 mV/s 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°
		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 ms in any two leads
and	(i)			WPW is not present
and	(j)			Brugada pattern is not present

or B.

	i.	(a and b and c) or (d and e)
and	ii.	(f) is true
and	iii.	Brugada pattern is not present

(a)		i.	QRS duration > LIM1 + 78 ms in any two leads
	and	ii.	QRS duration > LIM1 + 83 ms 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 ms
(e)			Delta confidence value in Lead V1 is 0
(f)			QRS axis is not between -30° and -120° or R > |S| in II

	(g)		i.	QRS axis is not between 100° and 135°
		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

4. **RBBB with left anterior fascicular block**

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

	(a)		i.	-120° < overall QRS axis < -30° and R ≤ |S| in II
		and	ii.	Inferior myocardial infarction is not present

5. **RBBB with RAD - possible left posterior fascicular block**

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

	(a)		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

6. **IV conduction defect**

Either A or B is true

A.

	(a)			In Lead I, R or R' > LIM1 + 68 ms
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/s
and	(e)			In V1, both Q and S have duration ≤ LIM1 + 68 ms or amplitude ≥ -1 mV
and	(f)			Brugada pattern is not present

B. Statement 1 to 5 are false, Brugada pattern is not present and from the following criteria either(a) is true or (b and c) is true.

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

7. **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.	LIM1 + 68 ms < 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-)
and	(c)			Brugada pattern is not present

8. **rSr'(V1) - probable normal variant**

Of the following criteria, either (a) or (b) is true and (c) and (d) are true

	(a)		i.	7 (a) (i) is true.
		and	ii.	QRS duration < LIM1 + 68 ms.
or	(b)		i.	In V1 or V2, 0.15mV < 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	(c)		i.	There is no atrial fibrillation or flutter
		or	ii.	There is atrial fibrillation or flutter and R' amplitude > 3 × max (P+, P-)
and	(d)			Brugada pattern is not present

8.1 Wolff-Parkinson-White Pattern

The diagnosis of WPW pattern is based on an algorithm developed by Fitzpatrick et al[a].

Criteria

A.						QRS duration > 103 ms
B.						PR interval < 185 ms
C.						The P axis value lies between -1° and 90° inclusive.
D.						Sum of delta wave confidences over all leads ≥ 100%
E.	1.		(a)			There is a 65% confidence of a delta wave in any 2 of leads I, II, III, aVL, aVF, V1, V2, V3, V4, V5, V6.
		and	(b)		i.	Sum of delta wave confidences over all leads ≥ 200%
				or	ii.	PR interval < 160 ms
or	2.		(a)			PR interval < 115 ms
		and	(b)		i.	There is a 60% confidence of a delta wave in any 2 of leads I, II, III, aVL, aVF, V1, V2, V3, V4, V5, V6.
				or	ii.	There is a 40% confidence of a delta wave in any 3 of leads I, II, III, aVL, aVF, V1, V2, V3, V4, V5, V6.

WPW pattern is present if all criteria A, B, C, D, E are met.

The statements are of the form:

[a] Fitzpatrick AP, Gonzales RP, Lesh MD, et al. New algorithm for the localization of accessory atrioventricular connections using a baseline electrocardiogram. J Am Coll Cardiol 1994;23:107-116.

WPW pattern – probable * accessory pathway

where * is the location and can be one of the following

- right posteroseptal
- midseptal
- anteroseptal
- right anterolateral
- right posterolateral
- left anterolateral
- left posteroseptal
- left posterolateral

Statements

1. **WPW pattern – probable right posteroseptal accessory pathway**

	(a)		i.	QRS transition between leads V1 and V2, or at V2 and Ramp > (|S amp| + 1.0 mV) in lead I
		or	ii.	QRS transition between lead V2 and V3, or at V3
		or	iii.	QRS transition between leads V3 and V4 and delta wave II ≥ 1.0 mV
and	(b)			Sum of delta wave polarities (II,III,aVF) ≤ -2

2. **WPW pattern – probable midseptal accessory pathway**

	(a)	1 (a) is true
and	(b)	-2 < Sum of delta wave polarities (II, III, aVF) < 2

3. **WPW pattern – probable anteroseptal accessory pathway**

	(a)	1 (a) is true
and	(b)	Sum of delta wave polarities (II, III, aVF) ≥ 2

4. **WPW pattern – probable right anterolateral accessory pathway**

	(a)		i.	QRS transition between leads V3 and V4 and delta wave in lead II < 1.0 mV
		or	ii.	QRS transition at or after lead V4
and	(b)		i.	If delta wave frontal axis ≥ 1°
		or	ii.	R amp in lead III ≥ 0

5. **WPW pattern – probable right posterolateral accessory pathway**

	(a)	4 (a) is true
and	(b)	4 (b) is false

6. **WPW pattern – probable left anterolateral accessory pathway**

	(a)		i.	QRS transition before or at lead V1
		or	ii.	QRS transition between leads V1 and V2, or at V2 and R amp ≤ (|S amp| + 1.0 mV) in lead I
and	(b)		i.	Sum of delta wave polarities in (II,III,aVF) ≥ 2
		or	ii.	R amp > |S amp| in aVL

7. **WPW pattern – probable left posteroseptal accessory pathway**

	(a)			6 (a) is true
and	(b)			6 (b) is false
and	(c)		i.	Sum of delta wave polarities in (II,III,aVF) < 0
		and	ii.	R amp > (|S amp| + 0.8 mV) in I

8. **WPW pattern – probable left posterolateral accessory pathway**

	(a)	6 (a) is true
and	(b)	6 (b) is false
and	(c)	7 (c) is false

8.2 Brugada Pattern

The Brugada pattern statement is implemented according to the criteria published in the Second Consensus Conference on the Brugada Syndrome[a].

Criteria

A	ST_j > 0.2 mV
B	R' amplitude > 0.2 mV
C	ST slope < -15°
D	T- amplitude < -0.05 mV
E	T morphology is +2

Statements

1. **Marked ST elevation – consider Brugada pattern**

	(a)	Atrial Flutter is not present
and	(b)	A and B and C and D and E are true in V1, V2 or V3

[a] Antzelevitch C, Brugada P, Borggrefe M, et al. Brugada Syndrome. Report of the Second Consensus Conference. Endorsed by the Heart Rhythm Society and the European Heart Rhythm Association. Circulation 2005;111:659-670.

9 Hypertrophy

9.1 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. The points are totalled 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 can be used for adults and children. An example is given for the upper limit of normal R wave amplitude in V5 for boys aged 11 to 18 years:

$$RV5 = [93.4 - 0.166 \times \text{age (months)}]^2$$

A complete set of equations is too detailed to print. For adults, there are separate equations for males and females while for children the continuous equations are also at times sex dependent and, on occasions, are 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 Oriental adults.

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 ≥ an age and sex dependent limit
ii.	|S| in V1 or V2 ≥ an age and sex dependent limit
iii.	R in V5 or V6 ≥ an age and sex dependent limit
iv.	The Lewis Index (RI + |S|III) - (RIII+ |S|I) > an age and sex dependent limit (for age 17 and over only)
v	The Sokolow Lyon Index |SV1| + RV5/V6 > an age and sex dependent limit (for age 17 and over only)

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

	Birth	17 years		50 years	
		Male	Female	Male	Female
R in I	1.3	1.5	1.5	1.6	1.4
R in aVL	0.9	1.1	0.9	1.3	1.2
S in V1,V2	3.0	4.0	3.5	2.5	2.0
R in V5, V6	3.25	4.0	2.5	2.5	2.2
Lewis Index	-	2.5	2.0	2.0	1.8
Sokolow Lyon Index	-	5.0	4.25	4.5	3.75

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) are ture

Score 1 point if i, iv and v are true.

NOTE

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

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.	Age ≥ 17 years
and	iii.	-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 section ***10 Myocardial Infarction***) in the corresponding lead.

Alternative Criteria

G. (4 - 5 points).

	i.	Age ≥ 17 years
	ii.	90 ms < the overall QRS duration < 120 ms
	iii.	The R or R' amplitude in aVL > 0.2 mV
	iv.	The sum of max (R,R') amplitude in aVL and max (S,S') amplitude in V3 > 2.8 mV

Score 4 points if i, ii, iii and iv are true.

Score 5 points if i, ii, iii and iv are true and ii and iv exceed lower thresholds significantly.

NOTE

- **Test G is an alternative to tests A to F if A-F did not result in diagnosis of LVH.**

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. **Left ventricular hypertrophy, possible digitalis effect**

	(a)	1 (a) is true
and	(b)	Patient is on digitalis

4. **Possible left ventricular hypertrophy, possible digitalis effect**

	(a)	2 (a) is true
and	(b)	Patient is on digitalis

5. **Left ventricular hypertrophy by voltage only**

	i.	LVH score ≥ 4 points
and	ii.	Criteria B-F are false or G is true
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 points
and	ii.	G or 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

9.2 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.

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

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

	Birth	Adolescence	Age 60 years
LIM1	1.6 mV	0.482 mV	0.36 mV
LIM2	2.5 mV	1.5 mV	
LIM3	3.14 mV	0.78 mV	0.56 mV
LIM4	2.17 mV	1.6 mV	
LIM5	10.9 mV	1.1 mV	
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.

A. (2 points).

			i.	In Lead I, either S or S' > LIM1
		and	ii.	In 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' > 2.5 × LIM1 with R >0.1 mV
		or	ii.	In V5, either S or S' > LIM2
		or	iii.	Age < 18 years and in V5 ,4 × max(S,S') > max (R,R') where max(S,S') > 1.0 mV

NOTE

- **If both A and B are true, count only B.**

C. (2 points).

	(a)		i.	In lead V1, the R or R' amplitude > LIM3
		and	ii.	T+ in V1 ≤ 0.7mV (age 12 – 30 years), or 0.5mV (age ≥ 30 years)
or	(b)		i.	In V4R, R > LIM4
		and	ii.	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).

	(a)		i.	In V1, the R/|S|amplitude ratio ≥ LIM5 with S > 0.1 mV
		or	ii.	In V1, Q and S = 0mV and age > 5 years
and	(b)			In V1, either R or R' > 0.4 mV,
and	(c)			T+ amplitude in V1 ≤ 0.5 mV

F. (3 points).

				In V1, |Q| > 0.1 mV and Q ≥ 25 ms, and R ≥ 0.25 mV with R-ST_j ≥ 0.04 mV and S = 0 mV

G. (1 point).

				In aVF, the P+ amplitude ≥ 0.3 mV

H. (1 point).

			i.	In aVF, the ST junction is negative
		or	ii.	In aVF, T- < -0.1 mV, and the T wave morphology is not +2

J. (3 points).

	(a)		i.	In V2, ST_j < 0.02 mV with downward slope < -5
		and	ii.	In V2, T- < -0.1 mV
		and	iii.	Age ≥ 5 years
		and	iv.	In aVF, ST_j < 0.15 mV
or	(b)		i.	In V2, ST_j < -0.15 mV with downward slope < 0
		and	ii.	In V2, T- < -0.1 mV
		and	iii.	Age < 5 years

K. (1 point)

	LIM6 < QRS axis < 270°

L. (1 point).

	i.	In all the Leads I, II, and III, |S| > 0.2 mV
and	ii.	QRS axis > 0°

M. (4 points).

	(a)		i.	Age > 5 days and < 9 years
		and	ii.	In V1, V5 and V6, T+ > 0.1 mV and T- = 0 mV
or	(b)		i.	Age ≤ 5 days
		and	ii.	In V1, T+ > 0.1 mV and T- = 0 mV
		and	iii.	There is left axis deviation

Statements

1. Right ventricular hypertrophy

	(a)	Score ≥ 5 points

2. Possible right ventricular hypertrophy

	(a)	4 ≤ score < 5 points

3. Right ventricular hypertrophy, possible digitalis effect

	(a)	1 (a) is true
and	(b)	Patient is on digitalis

4. Possible right ventricular hypertrophy, possible digitalis effect

	(a)	2 (a) is true
and	(b)	Patient is on digitalis

9.3 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 points
		and	ii.	The maximum QRS vector (in I, aVF, V2) > age dependent limit B (see table).

Table of age dependent limits for max QRS vector

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

2. **Possible biventricular hypertrophy**

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

FOR YOUR NOTES

FOR YOUR NOTES

10 Myocardial Infarction

In this section, there are three types of criteria used in the diagnosis of myocardial infarction. The first type uses criteria for acute ST elevation myocardial infarction (STEMI) in the absence of LBBB. The second uses Sgarbossa's criteria for an acute MI in the presence of LBBB and the third uses criteria based on Q waves and ST-T amplitudes.

STEMI criteria are modelled on the ACC/ESC criteria in the absence of LBBB and Sgarbossa's criteria in the presence of LBBB.

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

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

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

10.1 STEMI Criteria

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

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
$20 \le age \le 60$	$(-1.0) \times$ age (in years) + 190
> 60	$(-1) \times 60 + 190 = 130$
< 20	$(-1) \times 20 + 190 = 170$

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

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[a] Joint ESC/ACC Committee. Myocardial infarction redefined. European Heart J 2000; 21:1502-1513.

[b] Thygesen K, et al. Universal definition of myocardial infarction. Circulation 2007;116:2634-2653.

[c] Macfarlane PW, et al. Modification of ACC/ESC criteria for acute myocardial infarction. J Electrocardiol 2004;37(Suppl):98-103.

[d] Macfarlane PW, et al. Evaluation of age and sex dependent criteria for ST elevation myocardial Infarction. Computers in Cardiology 2007;34:293-296.

These criteria are omitted under the following conditions:

- presence of WPW
- presence of LBBB
- QRS duration > 180 ms
- age ≤ 18 years
- 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)

10.2 Sgarbossa's Criteria

If LBBB is present, then the criteria for acute MI as given by Sgarbossa et al[a] are used.

The criteria are as follows:

- ST segment elevation > 1 mm that is concordant with the QRS complex (score 5)
- ST segment depression > 1 mm in leads V1, V2 or V3 (score 3)
- ST segment elevation > 5 mm that is discordant with the QRS complex (score 2)

The ST amplitude is measured at the J point as per the original publication[a]. According to Sgarbossa et al, any score > 3 implies an acute MI. The higher the score, the greater the likelihood of an acute MI.

These criteria are omitted under the following conditions:

- Presence of WPW
- Presence of Brugada pattern
- QRS duration > 180 ms
- Heart Rate > 150 bpm

10.3 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 paediatric age group, in which criteria for abnormal Q waves are checked and if any are found to be true, the statement "Abnormal Q waves" is produced.It should also be noted that neural network software is used in addition to the criteria listed overleaf.

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[a] Sgarbossa EB, Pinski SL, Barbagelata A, et al. Electrocardiographic diagnosis of evolving acute myocardial infarction in the presence of left bundle branch block. N Engl J Med 1996;334:481–7

A neural network utilising 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 utilised. 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 or |Q/R| > 1/5
and	(b)			|Q| > 0.11 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 > 0.02s
and	(b)			|Q| > 0.075 mV
and	(c)			Peak to peak QRS > 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| > 0.1mV
and	(b)			QRS axis < 0°
and	(c)			Age > 18 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.
		and	iv.	Age > 18 years
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
		and	iii.	Age > 18 years

Q7

	(a)			T axis < -10°
and	(b)			R < 0.90 mV in II
and	(c)			|Q/R| > 1/5 and |Q| > 0.05 mV in any 2 of II, III, or aVF
and	(d)			Rhythm is not atrial flutter
and	(e)			Age > 18 years

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

10.4 Inferior Infarction Statements

The tests for Q1 to Q4 are caried out on II, III, 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

and C.

	(a)	LBBB is not present

2. **Inferior infarct – age undetermined**

	(a)	1 A (a) is true
and	(b)	STEMI criteria are not met
and	(c)	LBBB is not present

3. **Possible inferior infarct – age undetermined**

	(a)	1 A (a) or 1A (b) is true
and	(b)	LBBB is present

4. **Small inferior Q waves: infarct cannot be excluded**

	(a)	1 A (a) is false and 1A (b) is true
and	(b)	STEMI criteria are not met
and	(c)	LBBB is not present

5. **Small inferior Q waves noted: probably normal ECG**

	(a)			4 is true
and	(b)		i.	There are no other diagnostic statements
		or	ii.	There is only one other diagnostic statement: Small lateral Q waves noted: probably normal ECG
and	(c)			There is no T wave inversion in the inferior leads
and	(d)			T axis > 5°
and	(e)		i.	In aVF, Q/R amplitude ratio < 0.5 and there is an R wave in aVF
		or	ii.	In aVF, S/R' amplitude ratio < 0.5 and the R wave in aVF < 0.05 mV and there is an R' wave in aVF
and	(f)			The rhythm is sinus

This statement replaces statement 4, if true.

6. **Abnormal Q waves of undetermined cause**

	(a)	If any of the previous statements is true
and	(b)	The age of the patient is less than 18 years

Replace the previous statements by this one, if true.

7. **Inferior Q waves may be due to cardiomyopathy**

	(a)			Any of the statements 2, 4 or 5 is true
and	(b)			The age of the patient is between 18 and 40 years
and	(c)		i.	There is a Q wave but no R or S waves in leads II or aVF
		or	ii.	There are Q equivalent waves and small R waves in II or aVF
and	(d)			There is no T wave inversion in leads II or aVF

Replace statement 2, 4 or 5 by this one, if true.

Inferior Infarction Statement Addition

8. **Q waves may be due to cardiomyopathy**

	(a)	If any of statements 1-6 is set
and	(b)	There is a clinical classification of cardiomyopathy
and	(c)	There is no T wave inversion in II or aVF

10.5 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.

2. **Lateral infarction – age undetermined**

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

3. **Possible lateral infarction – age undetermined**

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

4. **Small lateral Q waves noted: probably normal ECG**

	(a)			3 is true
and	(b)		i.	There are no other diagnostic statements
		or	ii.	There is only one other diagnostic statement: Small inferior Q waves noted: probably normal ECG
and	(c)			There is no T wave inversion in the lateral leads
and	(d)			T axis < 85°
and	(e)		i.	In I, Q/R amplitude ratio < 0.5 and there is an R wave in I
		or	ii.	In I, S/R’ amplitude ratio < 0.5 and the R wave in I < 0.05 mV and there is an R’ wave in I.
and	(f)			The rhythm is sinus

This statement replaces statement 3, if true.

5. **Abnormal Q waves of undetermined cause**

	(a)	If any of the previous statements is set true
and	(b)	The age of the patient is less than 18 years

Replace the previous statements by this one, if true.

6. **Lateral Q waves may be due to cardiomyopathy**

	(a)	Any of the statement 2, 3 or 4 is true
and	(b)	The age of the patient is between 18 and 40 years
and	(c)	There is a Q wave but no R or S waves in lead I
and	(d)	There is no T wave inversion in lead I

Replace statement 2, 3 or 4 by this one, if true.

Lateral Infarction Statement Addition

7. **Q waves may be due to cardiomyopathy**

	(a)	If any of statements 1 - 5 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 mV
		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 > 20 ms
		and	iii.	|Q/R| > 1/5
		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 > 20 ms
		and	iv.	|S/R'| > 1/5

VQ3

	(a)		i.	R < 0.11 mV
		and	ii.	R' < 2 × R amplitude, or RBBB is present
		and	iii.	|R/S| < 0.125
		and	iv.	The peak to peak amplitude > 0.2 mV
		and	v.	RVH is not present

VQ4

	(a)		i.	R in V(n) - R in V(n+1) > 0.05mV in the adjacent precordial lead, (e.g. V3 < V2)
		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 and IVCD are not present
		and	iii.	ST in V2 ≤ 0.12mV or ST < 1/2 T+
or	(b)		i.	R < 0.3mV 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, implanted pacemaker, pulmonary embolism, post-operative changes, cardiomyopathy or other/not known
		and	iv.	RBBB and 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

10.6 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)		i.	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

2. **Anteroseptal infarct – age undetermined**

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

3. **Possible anteroseptal infarct – age undetermined**

	(a)	1 A (a) is false and 1 A (b) is true
and	(b)	STEMI criteria are 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 of rheumatic heart disease
and	(e)	The age of the patient is 18 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 Q waves of undetermined cause**

	(a)	Any of the above statements is true
and	(b)	The age of the patient is less than 18 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)	If 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 a classification 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 of the statements 1-4 is set true
and	(b)	LVH is present with secondary ST-T changes and |S| in V2 > 0.2mV
and	(c)	ST < 1/2 T+ in V2 and V3
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 18 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 of the 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 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

10.7 Anterior Myocardial Infarction Statements

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

I. ***** ANTERIOR INFARCT – POSSIBLY ACUTE *****

A. Presence of Q waves

	(a)		i.	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 for V2, V3 and V3, V4
		or	iii.	VQ2 (a) is true in V3 or V4 with QRVH false in V1
		or	iv.	VQ2 (b) is true in V3 or V4 or VQ3 is true in V3 or V4 (except for females with T+ > 0.05 mV in V3 and T morphology = 1 in V3, where there is not a clinical classification of myocardial infarction)
		or	v.	VQ4 is true for V2, V3 or V3, V4 for males or for V4, V5 for males or females
		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.

2. **Anterior infarct – age undetermined**

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

or B.

	(a)	If statement 1or 2 is true
and	(b)	ST < 1/2 T+ in V3 and V4
and	(c)	Clockwise cardiac rotation is true, and VQ1 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 set 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 of rheumatic heart disease
and	(e)	The age of the patient is 18 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 Q waves of undetermined cause**

	(a)	Any of the above statements is true
and	(b)	The age of the patient is less than 18 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 above statements is true
and	(b)	There is moderate or high T+ in V3, 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 set true or VQ3 is true
and	(b)	LVH is present with secondary ST-T changes and |S| in V2 > 0.2 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 18 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)	7 (a) to (c) are true
and	(b)	There is a clinical classification of respiratory disease but not of myocardial infarction

The above statement replaces 1-4, if true.

10. **Poor R wave progression**

	(a)		i.	VQ3 or 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
		and	iv.	There is no significant ST elevation V2-V4
		and	v.	0.25 mV < R ≤ 0.4 mV in V4 for males or 0.25 mV < R ≤ 0.3 mV in V4 for females
		and	vi.	There is no LVH
		and	vii.	There is no inferior or lateral infarction
or	(b)		i.	VQ3 or VQ4 or PRWP is true
		and	ii.	R or R' in I > 0.4 mV and R or R’ in V4 < 0.25 mV
		and	iii.	There is no T inversion in V2-V4
		and	iv.	There is no significant ST elevation V2-V4
		and	v.	There is no LVH
		and	vi.	There is no inferior or lateral infarction

Anterior Infarction Statement Addition

1. **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

10.8 Septal Infarction Statements

1. ***** SEPTAL INFARCT – POSSIBLY ACUTE *****

A. Presence of Q waves

	(a)	VQ1 is true for V2 with QRVH false in V1
or	(b)	There is VQ2(a) in V2 with QRVH false in V1

and B. Acute ST elevation MI suspected

	(a)	The STEMI criteria are met

2. **Cannot rule out septal infarct – age undetermined**

A.

	(a)	1 A (a) or (b) is true
and	(b)	LVH is present
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 either congenital heart disease or of rheumatic heart disease
and	(e)	The age of the patient is 18 years or over

or B.

	(a)			1 A (a) or (b) is true
and	(b)			STEMI criteria are not met
and	(c)		i.	**RBBB** or **RVH** is present
		or	ii.	LVH with repolarisation is not present and there is T inversion in V2

The above statement replaces 1, if true.

3. **Q in V1/V2 may be normal variant but septal infarct cannot be excluded**

	(a)	1 A (a) or (b) is true
and	(b)	STEMI criteria are not met
and	(c)	**RBBB**, **RVH** and **LVH** are not present
and	(d)	The R and R' amplitude in V3 ≤ 0.3 mV
and	(e)	There is no T inversion in V2

4. **Q in V1/V2 may be due to lead placement error though septal infarct cannot be excluded**

	(a)	1 A (a) or (b) is true
and	(b)	STEMI criteria are not met
and	(c)	**RBBB**, **RVH** and **LVH** are not present
and	(d)	R or R' amplitude in V3 > 0.3 mV
and	(e)	There is no T inversion in V2

5. **Q in V1/V2 may be due to LVH though septal infarct cannot be excluded**

	(a)	1 A (a) or (b) is true
and	(b)	2 is false
and	(c)	STEMI criteria are not met
and	(d)	**LVH** with repolarisation is present
and	(e)	**RBBB** and **RVH** are not present

6. **Abnormal Q waves of undetermined cause**

	(a)	Any of the above statements is true
and	(b)	The age of the patient is less than 18 years

The above statement replaces any of 1-5, if true.

7. **Septal QRS changes may be due to ventricular hypertrophy**

	(a)	Any of the above statements 2-5 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 statements 2-5, if true.

8. **Septal QRS changes may be due to corrected transposition**

	(a)	If any of the above statements 2-5 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 statements 2-5, if true.

9. **QRS changes in V2 probably due to LVH but cannot rule out septal infarct**

	(a)	If any of the statements 2-5 is set true
and	(b)	LVH is present 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 of rheumatic heart disease
and	(e)	The age of the patient is 18 years or over

The above statement replaces any of 2-5 if true.

10. **Poor R wave progression – cannot rule out septal infarct**

	(a)	If any of the statements 2-5 is set true
and	(b)	ST < 1/2 T+ in V3 and V4
and	(c)	Clockwise cardiac rotation is true, and VQ1 false in V4
and	(d)	The age of the patient is 18 years or over

The above statement replaces any of 2-5, if true.

11. **Poor R wave progression may be due to pulmonary disease**

	(a)	10 (a) to (c) are true
and	(b)	There is a clinical classification of respiratory disease but not of myocardial infarction
and	(c)	The age of the patient is 18 years or over

The above statement replaces 2-5, if true.

Septal Infarction Statement Addition

1. **Q waves may be due to cardiomyopathy**

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

10.9 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.

10.10 Anterolateral Myocardial Infarction Statements

This section is entered if the following criteria are met.

	(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.

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 for 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.

2. **Anterolateral infarct – age undetermined**

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

3. **Possible anterolateral infarct – age undetermined**

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

4. **Abnormal Q waves of undetermined cause**

	(a)	If any of the previous statements is set true
and	(b)	The age of the patient is less than 18 years

Anterolateral Infarction Statement Addition

1. **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

10.11 Extensive Myocardial Infarction

This section is entered if the following criteria are met.

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

1. ***** EXTENSIVE INFARCT – POSSIBLY ACUTE *****

	(a)		i.	There is inferior or lateral infarction
		and	ii.	There is anteroseptal infarction
and	(b)			The STEMI criteria are met.

2. **Extensive infarct – age undetermined**

	(a)		i.	There is inferior or lateral infarction
		and	ii.	There is anteroseptal infarction
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 anteroseptal leads
and	(b)	The STEMI criteria are not met

4. **Abnormal Q waves of undetermined cause**

	(a)	If any of the previous statements is set true
and	(b)	The age of the patient is less than 18 years

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

Extensive Infarction Statement Addition

1. **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

11 ST Abnormalities

Criteria

There are 2 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 the Chapter ***10 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 paediatric 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 3 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, Brugada pattern 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)		ST_j < -0.1 mV and ST_j >T- + 0.05 mV in V2-V3, and if this is only true for V3 then there is no LVH with repolarization abnormality.
and	(b)		There is an ACUTE inferior MI
and	(c)		There is not RBBB or Brugada pattern

9. **Marked anteroseptal ST depression**

(a)		i.	ST < -0.3 mV in any of V1 - V4 with corresponding ST slope negative, and RBBB and LBBB are false and there is no RVH with repolarization abnormality. In addition, if only V3 and V4 satisfy these criteria, then there is no LVH with repolarization abnormality.
	or	ii.	In V2 and V3, ST < -0.1 mV with corresponding ST slope negative, |ST-T-| < 0.2 mV and there is no acute inferior infarct and RBBB, IVCD, Brugada pattern and (definite) RVH are not present.
	or	iii.	ST junction < -0.2 mV in V2 and there is ST elevation in any limb lead (as defined for STEMI) and there is no RBBB nor RVH with repolarisation
	or	iv.	ST junction < -0.1 mV and ST slope > 75 and T+ > 0.75 mV and T+ > max(R,R') in V2 and V3

10. **Marked inferior ST depression**

	(a)	ST junction < -0.2 mV and ST slope < 20° in 2 contiguous limb leads and |S| > |ST|
and	(b)	There is no LBBB
and	(c)	There is no LVH with repolarisation

11. **Marked lateral ST depression**

	(a)	ST junction < -0.1 mV and ST slope < 0° in lateral leads I, aVL, V5 and V6.
and	(b)	There is no LBBB
and	(c)	There is no LVH with repolarisation

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 operative 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)		i.	There is marked inferior and anterolateral ST elevation
		and	ii.	There is a high ST elevation score in all anteroseptal leads
		and	iii.	There is no QRS notching

5. **consider pericarditis**

	(a)			Statements 1-4 are false
and	(b)			There is moderate inferior and anterolateral ST elevation
and	(c)			There is a high ST elevation score in all anteroseptal leads
and	(d)			There is no QRS notching

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)		i.	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
and	(c)			Age ≤ 55 years

9. **possible early repolarization**

	(a)			Statements 1-8 are false
and	(b)			There is moderate ST elevation
and	(c)			Age ≤ 55 years

10. **is nonspecific**

	(a)			Statements 1-9 are false
and	(b)			There is marked or moderate ST elevation
and	(c)			Age > 55 years

11.1 ST Depression

The following ST depression statements are only reported if the patient is ≥ 18 years and the heart rate is < 150 bpm. If any of the following sets of criteria is true, then the appropriate reason (8 to 11) is printed together with the statement.

11. **is probably reciprocal to inferior infarct**

	(a)			There is anteroseptal ST depression as described in Reason 8
and	(b)			There is an acute inferior infarct

12. **accompanies the infarct**

	(a)		i.	There is marked anteroseptal ST depression as described in Reason 9.
		or	ii.	There is marked inferior ST depression as described in Reason 10.
		or	iii.	There is marked lateral ST depression as described in Reason 11.
and	(b)			There is an acute infarct in another wall (e.g. in ST elevation in one area and ST depression in another)

13. **, CONSIDER ACUTE INFARCT**

	(a)			Statements 11 and 12 are FALSE
and	(b)		i.	There is marked anteroseptal depression as described in Reason 9(a) i, ii or iii.
		or	ii.	There is marked inferior ST depression as described in Reason 10.
		or	iii.	There is marked lateral ST depression as described in Reason 11.

14. **, CONSIDER ACUTE INFARCT (proximal LAD occlusion)**

	(a)			Statement 11 is FALSE
and	(b)		i.	There is marked anteroseptal ST depression as described in Reason 9 (a) (iv).
		and	ii.	ST is positive in aVR
		and	iii.	Overall QRS duration < 120 ms.
		and	iv.	There is no acute inferior infarct

FOR YOUR NOTES

12 ST-T Abnormalities (Ischaemia etc)

The criteria for ST-T abnormalities 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.

Define an ST-T abnormality in the lead combinations as follows:

Inferior leads

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

Lateral leads

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

Anteroseptal leads

	(a)	There is ST depression or T wave inversion in anteroseptal leads
and	(b)	There is not (anterior) septal or anterior infarction
and	(c)	None of the following is true: **WPW**, **RBBB**, **RBBB with left anterior fascicular block**, **RBBB with left posterior fascicular block**, **Extensive IVCD** or **Brugada pattern**

Anterior leads

	(a)	There is no ST-T abnormality in the anteroseptal leads
and	(b)	There is ST depression or T wave inversion in the anterior leads
and	(c)	None of the following is true: **WPW**, **RBBB**, **RBBB with left anterior fascicular block**, **RBBB with left posterior fascicular block**, **Extensive IVCD**, **LBBB** or **Brugada pattern**

Septal leads

	(a)	There is no ST-T abnormality in the anteroseptal or anterior leads
and	(b)	There is ST depression or T wave inversion in the septal leads
and	(c)	There is not anteroseptal or anterior or septal infarction
and	(d)	None of the following is true: **WPW**, **RBBB**, **RBBB with left anterior fascicular block**, **RBBB with left posterior fascicular block**, **Extensive IVCD** or **Brugada pattern**

Anterolateral leads

(a)	There is an ST and/or T wave abnormality in both anterior and lateral leads as defined above

Widespread

(a)	There is an ST and/or T wave abnormality in the inferiorleads and either the anterolateral or lateral leads togetherwith septal, anteroseptal or anterior leads

Statements (Reasons)

There are several possible 'reason' statements that can be produced, namely:

1. *** ST abnormality**
2. **ST junctional depression**
3. **Widespread ST abnormality**
4. *** T wave abnormality**
5. **Widespread T wave abnormality**
6. *** ST-T abnormality**
7. **Widespread ST-T abnormality**

The location of the abnormality, denoted *, can be chosen from the following:

- Inferior
- Lateral
- Anteroseptal
- Anterior
- Septal
- Anterolateral

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

NOTE

- **The 'reason' statements are essentially integral to the main diagnostic statement which would be meaningless if not preceded by a reason.**

Statements

If any of the above 'reason' statements 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 abnormality may be due to the hypertrophy and/or ischemia

In the paediatric age range, statements involving "Myocardial Ischaemia" are suppressed and are replaced by an appropriate statement, e.g. "Non-Specific".

1. **is nonspecific**

	(a)			There is an T wave abnormality in any lead group
and	(b)			There is demand pacemaker activity

2. **may be due to the hypertrophy and/or ischemia**

	(a)			LVH or RVH or BVH
and	(b)			ST-T abnormality
and	(c)		i.	Male ≥ 30 years
		or	ii.	Female ≥ 40 years
and	(d)			Patient is not on digitalis

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

	(a)			Criteria 2 (a-c) are true
and	(b)			Patient is on digitalis

4. **is probably due to the ventricular hypertrophy**

	(a)			LVH or RVH or BVH
and	(b)			ST-T abnormality
and	(c)		i.	Male < 30 years
		or	ii.	Female < 40 years
and	(d)			Patient is not on digitalis

5. **is probably due to the ventricular hypertrophy/digitalis effect**

	(a)			Criteria 4 (a-c) are true
and	(b)			Patient is on digitalis

6. **may be due to myocardial ischemia**

	(a)			There is ST-T abnormality 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 abnormality

7. **suggests 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. **is 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 is ST-T abnormality in the (antero) septal leads
		or	ii.	There is moderate ST-T abnormality in certain combinations of leads

9. **suggests myocardial injury/ischemia**

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

10. **is probably due to cardiac surgery**

	(a)			Clinical classification is post operative cardiac surgery
and	(b)		i.	There is widespread T wave inversion
		or	ii.	There is T wave abnormality 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 oranteroseptal leads
and	(b)		T- < -1.0 mV in V3, V4 or V5

12. **is consistent with endocrine disease**

	(a)		T wave abnormality (but not in anteroseptal leads only)
and	(b)		Clinical classification is endocrine disease
and	(c)		The heart rate < 60 bpm
and	(d)		The patient is not on digitalis

13. **is possibly secondary to hypertension**

	(a)		Moderate T wave abnormality in the inferior and/or lateral leads
and	(b)		Clinical classification is hypertension
and	(c)		Patient is not on digitalis

14. **is possibly secondary to hypertension/digitalis effect**

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

15. **may be secondary to hypertension/ischemia**

	(a)	Moderate T wave abnormality including inferior and lateral leads in addition to T wave abnormality 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. **is possibly secondary to congenital heart disease**

	(a)	There is ST and/or T wave abnormality
and	(b)	Clinical classification is congenital heart disease
and	(c)	Patient is not on digitalis

18. **is possibly secondary to valvular heart disease**

	(a)	There is ST and/or T wave abnormality
and	(b)	Clinical classification is rheumatic heart disease
and	(c)	Patient is not on digitalis

19. **is possibly secondary to valvular heart disease/digitalis**

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

20. **is possibly secondary to respiratory disease**

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

21. **is age related : consider juvenile T waves**

	(a)	T wave abnormality in (anterior) septal leads
and	(b)	Age < 18 years

22. **is non-specific: may be normal for age and race**

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

23. **may be age and gender related : consider normal variant**

	(a)			T wave abnormality in the inferior leads with or without changes in the lateral 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 ischaemia

24. **is 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 ischaemia
and	(c)	Patient is on digitalis
and	(d)	Clinical classification is not pulmonary embolism orpost-operative with certain groups of ST-T abnormalities

25. **suggests myocardial ischemia**

	(a)	Marked T wave abnormality in any group or groups of leads
and	(b)	Clinical classification is myocardial infarction or myocardial ischaemia
and	(c)	Patient is not on digitalis

26. **suggests 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 abnormality 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 ischaemia
and	(e)	Age > 30 years if male or age > 40 years if female

28. **suggests possible myocardial ischemia/digitalis effect**

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

29. **is age and gender related**

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

30. **is age and gender related – possible digitalis effect**

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

31. **is consistent with myocardial ischemia**

	(a)	Moderate ST and/or T wave abnormality in any group or group of leads
and	(b)	Clinical classification of myocardial infarction or myocardial ischaemia
and	(c)	Patient is not on digitalis

32. **is consistent with ischemia/digitalis effect**

	(a)	31 (a) and (b) is 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. **is 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. **is borderline for age and gender**

	(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. **is borderline for age and gender – possible digitalis effect**

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

37. **is consistent with digitalis effect**

	(a)	None of the previous statement is true
and	(b)	There is widespread borderline ST and/or T wave abnormality
and	(c)	Patient is on digitalis

38. **is probably due to digitalis effect**

	(a)	There is borderline ST and/or T wave abnormality in any group of leads
and	(b)	Patient is on digitalis

39. **suggests digitalis effect/ischemia**

	(a)	None of the previous statements is true
and	(b)	Patient is on digitalis
and	(c)	Age ≥ 35 years if female or age ≥ 30 years if male

40. **is 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 statement is true
and	(b)	There is widespread borderline ST and/or T wave abnormality

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 pattern 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)

13 Miscellaneous

13.1 Low QRS Voltages

Statements

1. **Low QRS voltages in limb leads**

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

2. **Low QRS voltages in precordial leads**

	(a)		i.	Female
		and	ii	Peak to peak QRS voltage < 0.8 mV for all of leads V1, V2, V3, V4, V5 and V6
or	(b)		i.	Male
		and	ii	Peak to peak QRS voltage < 1.0 mV for all of leads V1, V2, V3, V4, V5 and V6

3. **Generalized low QRS voltages**

	(a)			Both statements 1 and 2 are true

4. **Generalized low QRS voltages – consider pericardial effusion**

	(a)			Peak to peak QRS voltage < 75% of thresholds specified in statements 1 and 2.

13.2 Tall T Waves

Statements

1. **Tall T waves – consider acute ischemia or hyperkalemia**

	(a)	Age ≥ 30 years
and	(b)	T+ amplitude > an age and sex dependent limit in all leads V3 to V5, as detailed in the table below
and	(c)	Left Bundle Branch Block is not present

2. **Tall T waves – consider hyperkalemia**

	(a)	Age < 30 years
and	(b)	T+ amplitude > an age and sex dependent limit in all leads V3 to V5, as detailed in the table below
and	(c)	Left Bundle Branch Block is not present

Table of age and sex dependent limits:

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

FOR YOUR NOTES

14 Critical Values

There are six critical value statements that can be generated by the analysis. Each critical value statement will be output based upon the presence of specific statements that appear on the report or if the heart rate exceeds an age related threshold. The available critical value statements are as follows:

1. **Consider Acute STEMI**

This 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 ++ = inferior, lateral, anteroseptal etc.

2. **Acute MI/Ischemia**

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

Marked ++ ST depression, CONSIDER ACUTE INFARCT

CONSIDER ACUTE INFARCT (proximal LAD occlusion)

suggests myocardial infarct

may be due to myocardial injury or CVA

suggests myocardial injury/ischemia

where ++ = inferior, lateral, anteroseptal

3. **Extreme Tachycardia**

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

Age range	Rates in beats/min
Birth - 28 days	213 → 230
29 days - 180 days	230
181 days - 17 years	230 → 150
≥ 18 years	150

4. **Extreme Bradycardia**

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

Age range	Rates in beats/min
Birth - 28 days	73 → 90
29 days - 365 days	90
1 year - 6 years	90 → 45
6 years - 12.5 years	45 → 40
> 12.5 years	40

5. **Significant Arrhythmia**

This statement 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

6. **Prolonged QTc Interval**

	(a)	QTc > 520 ms
and	(b)	Overall QRS duration < 120 ms
and	(c)	Heart rate ≤ 125 bpm

15 Rhythm Statements

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.

15.1 Dominant Rhythm Statements

Sinus rhythm
Sinus tachycardia
Sinus bradycardia
Sinus arrhythmia
Sinus tachycardia with sinus arrhythmia
Sinus bradycardia with sinus arrhythmia
Atrial tachycardia
Atrial flutter
Atrial fibrillation
Junctional rhythm
Accelerated junctional rhythm
Junctional bradycardia
Atrial pacing
Ventricular pacing
A-V sequential pacemaker
Pacemaker rhythm
Possible ectopic atrial rhythm
Possible ectopic atrial tachycardia
Possible ectopic atrial bradycardia
Irregular ectopic atrial rhythm
Irregular ectopic atrial tachycardia
Irregular ectopic atrial bradycardia
Probable atrial tachycardia
Probable sinus tachycardia
Probable supraventricular tachycardia
Marked sinus bradycardia
Probable atrial flutter
Probable atrial fibrillation
Probable junctional rhythm
Probable accelerated junctional rhythm
Probable ventricular tachycardia
Wide QRS tachycardia
Accelerated idioventricular rhythm
Possible idioventricular rhythm
Possible atrial flutter
Possible junctional rhythm
Possible accelerated junctional rhythm

Possible junctional bradycardia
A-V dissociation
Undetermined rhythm
Regular supraventricular rhythm
Irregular supraventricular rhythm

15.2 Supplementary Rhythm Statements

with frequent PVCs
with multifocal PVCs
with frequent multifocal PVCs
with interpolated PVC(s)
with multifocal interpolated PVCs
with PVC(s)
with PAC(s)
with frequent PACs
with aberrantly conducted supraventricular complexes
with 1st degree A-V block
with borderline 1st degree A-V block
with 2nd degree A-V block, Mobitz I (Wenckebach)
with 2nd degree A-V block, Mobitz II
with 2:1 A-V block
with 3:1 A-V block
with 4:1 A-V block
with high degree A-V block
with varying 2nd degree A-V block
with complete A-V block
with 2nd degree (Mobitz II) SA Block
with bigeminal PACs
with bigeminal PVCs
Demand atrial pacing
Demand pacing
with fusion complexes
with non-sustained ventricular tachycardia
with intermittent conduction defect
with paroxysmal idioventricular rhythm
with unclassified aberrant complexes
with undetermined ectopic complexes
with undetermined irregularity

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

or aberrant ventricular conduction
with rapid ventricular response
with uncontrolled ventricular response
with slow ventricular response

16 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**

FOR YOUR NOTES

17 Measurement Matrix

The electrocardiographs can be programmed so that the Measurement Matrix is written out after the analysis report. The following pages contain explanations of the numerical values in the **Measurement Matrix**.

The **Measurement Matrix** consists of 12 columns which contain measurements for the twelve standard leads. These columns are labelled I, II, III, aVR, aVL, aVF, V1, V2, V3, V4, V5, V6. The meaning of the measurements is explained below, row by row:

Pon	Time in milliseconds from the beginning of the representative beat to the beginning of the P wave.
Pdur	P wave duration in milliseconds.
QRSon	Time in milliseconds from the beginning of the representative beat to the beginning of the QRS complex.
QRSdur	QRS duration in milliseconds.
Qdur	Q wave duration in milliseconds.
Rdur	R wave duration in milliseconds.
Sdur	S wave duration in milliseconds.
R'dur	R' wave duration in milliseconds.
S'dur	S' wave duration in milliseconds.
P+dur	P+ wave duration in milliseconds.
QRSdef	Intrinsicoid deflection time.
P+amp	P+ wave amplitude in microvolts.
P-amp	P- wave amplitude in microvolts.
QRSp2p	Peak to peak amplitude of the QRS complex.
Qamp	Q wave amplitude in microvolts.
Ramp	R wave amplitude in microvolts.
Samp	S wave amplitude in microvolts.
R'amp	R' wave amplitude in microvolts.
S'amp	S' wave amplitude in microvolts.
STamp	ST wave amplitude in microvolts.
2/8STT	Amplitude in microvolts at a point which is 2/8 of the ST-T interval.
3/8STT	Amplitude in microvolts at a point which is 3/8 of the ST-T interval.
T+amp	T+ wave amplitude in microvolts.
T-amp	T- wave amplitude in microvolts.
QRSarea	Total area of the QRS complex in microvolts/millisecond,
Rnotch	R wave notch count.

DWconf	Probability (in %) of the presence of a delta wave.
STslope	ST slope in degrees.
Ton	Time in milliseconds from the beginning of the representative beat to the beginning of the T wave.
Tdur	T wave duration in milliseconds.
T+dur	T+ wave duration in milliseconds.
QTint	QT interval in milliseconds.

18 List of Statements

The complete list of statements produced by the Glasgow Program is listed below.

18.1 Preliminary Comments

Possible faulty V2 - omitted from analysis

Possible faulty V3 - omitted from analysis

Possible faulty V4 - omitted from analysis

Possible faulty V5 - omitted from analysis

Possible faulty V6 - omitted from analysis

Possible sequence error: V1, V2 omitted

Possible sequence error: V2, V3 omitted

Possible sequence error: V3, V4 omitted

Possible sequence error: V4, V5 omitted

Possible sequence error: V5, V6 omitted

Lead(s) unsuitable for analysis:

~ I

~ II

~ III

~ aVR

~ aVL

~ aVF

~ V1

~ V2

~ V3

~ V4

~ V5

~ V6

~ V4R

--- Possible measurement error ---

V1/V2 are at least one interspace too high and have been omitted from the analysis

18.2 Lead Reversal/Dextrocardia

--- Possible arm lead reversal – hence only aVF, V1 – V6 analyzed ---

--- Suggests dextrocardia ---

--- Possible limb lead reversal – hence only V1-V6 analyzed ---

--- Possible arm/leg lead interchange – hence only V1-V6 analyzed ---

18.3 Rhythm Related

If rhythm is confirmed, the following report may not be valid

18.4 Demographic Related

--- Invalid clinical data entry ---

--- Invalid medication entry ---

--- Interpretation made without knowing patient's gender ---

--- Interpretation made without knowing patient's age ---

-- Interpretation made without knowing patient's gender/age --

--- Interpretation based on pediatric criteria ---

18.5 Restricted Analysis

Pacemaker rhythm - no further analysis

--- No further analysis due to lack of dominant QRS ---

--- Similar QRS in V leads ---

--- Technically unsatisfactory tracing ---

18.6 Intervals

Short PR interval

with 1st degree A-V block

with borderline 1st degree A-V block

Borderline prolonged QT interval

Prolonged QT – consider ischemia, electrolyte imbalance, drug effects

Short QT interval

18.7 Atrial Abnormalities

Possible right atrial abnormality

Consider left atrial abnormality

Possible right atrial abnormality consistent with pulmonary disease

Possible left atrial abnormality

Possible biatrial enlargement

18.8 QRS Axis Deviation

Indeterminate axis

Leftward axis

Left axis deviation

Marked left axis deviation

QRS axis leftward for age

Rightward axis

Right axis deviation

Marked right axis deviation

Left anterior fascicular block

Possible left anterior fascicular block

Possible left posterior fascicular block

Severe right axis deviation

18.9 Conduction Defects

Left bundle branch block

Incomplete LBBB

Right bundle branch block

RBBB with left anterior fascicular block

RBBB with RAD - possible left posterior fascicular block

IV conduction defect

Incomplete RBBB

rSr’(V1) - probable normal variant

18.10 WPW Pattern

WPW pattern – probable right posteroseptal accessory pathway

WPW pattern – probable midseptal accessory pathway

WPW pattern – probable anteroseptal accessory pathway

WPW pattern – probable right anterolateral accessory pathway

WPW pattern – probable right posterolateral accessory pathway

WPW pattern – probable left anterolateral accessory pathway

WPW pattern – probable left posteroseptal accessory pathway

WPW pattern – probable left posterolateral accessory pathway

18.11 Brugada Pattern

Marked ST elevation - consider Brugada pattern

18.12 Hypertrophy

Left ventricular hypertrophy

Possible left ventricular hypertrophy

Left ventricular hypertrophy, possible digitalis effect

Possible left ventricular hypertrophy, possible digitalis effect

Left ventricular hypertrophy by voltage only

Borderline high QRS voltage – probable normal variant

Right ventricular hypertrophy

Possible right ventricular hypertrophy

Right ventricular hypertrophy, possible digitalis effect

Possible right ventricular hypertrophy, possible digitalis effect

Biventricular hypertrophy

Possible biventricular hypertrophy

18.13 Myocardial Infarction

*** INFERIOR INFARCT – POSSIBLY ACUTE ***

Inferior infarct – age undetermined

Possible inferior infarct – age undetermined

Small inferior Q waves: infarct cannot be excluded

Small inferior Q waves noted: probably normal ECG

Abnormal Q waves of undetermined cause

Inferior Q waves may be due to cardiomyopathy

Q waves may be due to cardiomyopathy

*** LATERAL INFARCT – POSSIBLY ACUTE ***

Lateral infarction – age undetermined

Possible lateral infarction – age undetermined

Small lateral Q waves noted: probably normal ECG

Abnormal Q waves of undetermined cause

Lateral Q waves may be due to cardiomyopathy

Q waves may be due to cardiomyopathy

*** ANTEROSEPTAL INFARCT – POSSIBLY ACUTE ***

Anteroseptal infarct – age undetermined

Possible anteroseptal infarct – age undetermined

Cannot rule out anteroseptal infarct – age undetermined

Abnormal Q waves of undetermined cause

Anteroseptal QRS changes may be due to ventricular hypertrophy

Anteroseptal QRS changes may be due to corrected transposition

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

Poor R wave progression – cannot rule out anteroseptal infarct

Poor R wave progression consistent with pulmonary disease

Q waves may be due to cardiomyopathy

*** ANTERIOR INFARCT – POSSIBLY ACUTE ***

Anterior infarct – age undetermined

Possible anterior infarct – age undetermined

Cannot rule out anterior infarct – age undetermined

Abnormal Q waves of undetermined cause

Anterior QRS changes may be due to ventricular hypertrophy

Anterior QRS changes may be due to corrected transposition

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

Anterior QRS changes are probably related to pulmonary disease

Poor R wave progression

Q waves may be due to cardiomyopathy

*** SEPTAL INFARCT – POSSIBLY ACUTE ***

Cannot rule out septal infarct – age undetermined

Q in V1/V2 may be normal variant but septal infarct cannot be excluded

Q in V1/V2 may be due to lead placement error though septal infarct cannot be excluded

Q in V1/V2 may be due to LVH though septal infarct cannot be excluded

Abnormal Q waves of undetermined cause

Septal QRS changes may be due to ventricular hypertrophy

Septal QRS changes may be due to corrected transposition

QRS changes in V2 probably due to LVH but cannot rule out septal infarct

Poor R wave progression – cannot rule out septal infarct

Poor R wave progression may be due to pulmonary disease

Q waves may be due to cardiomyopathy

Possible posterior infarct – age undetermined

Possible posterior extension of infarct

Tall R V1/V2 probably reflect the infarct

*** ANTEROLATERAL INFARCT – POSSIBLY ACUTE ***

Anterolateral infarct – age undetermined

Possible anterolateral infarct – age undetermined

Abnormal Q waves of undetermined cause

Q waves may be due to cardiomyopathy

*** EXTENSIVE INFARCT – POSSIBLY ACUTE ***

Extensive infarct – age undetermined

Possible extensive infarct – age undetermined

Abnormal Q waves of undetermined cause

Q waves may be due to cardiomyopathy

18.14 ST Abnormalities

Inferior ST elevation

Lateral ST elevation

Anteroseptal ST elevation

Anterior ST elevation

Septal ST elevation

Extensive ST elevation

Anterolateral ST elevation

Anteroseptal ST depression
Marked anteroseptal ST depression
Marked inferior ST depression
Marked lateral ST depression
, CONSIDER ACUTE INFARCT
suggests post-operative pericarditis
probable post-operative pericarditis
suggests pericarditis
consider pericarditis
is consistent with pericarditis
cannot rule out myocardial injury
suggests early repolarization
possible early repolarization
is nonspecific
is probably reciprocal to inferior infarct
accompanies the infarct
, CONSIDER ACUTE INFARCT
, CONSIDER ACUTE INFARCT (proximal LAD occlusion)

18.15 ST-T Changes (Ischemia)

* ST abnormality
ST junctional depression
Widespread ST abnormality
* T wave abnormality
Widespread T wave abnormality
* ST-T abnormality
Widespread ST-T abnormality
is nonspecific
may be due to the hypertrophy and/or ischemia
may be due to the hypertrophy and/or ischemia/digitalis effect
is probably due to the ventricular hypertrophy
is probably due to the ventricular hypertrophy/digitalis effect
may be due to myocardial ischemia
suggests myocardial infarct
is consistent with pulmonary embolism
suggests myocardial injury/ischemia
is probably due to cardiac surgery
may be due to myocardial infarct or CVA
is consistent with endocrine disease
is possibly secondary to hypertension
is possibly secondary to hypertension/digitalis effect
may be secondary to hypertension/ischemia
may be due to digitalis/hypertension
is possibly secondary to congenital heart disease

is possibly secondary to valvular heart disease

is possibly secondary to valvular heart disease/digitalis

is possibly secondary to respiratory disease

is age related : consider juvenile T waves

is non-specific: may be normal for age and race

may be age and gender related : consider normal variant

is consistent with digitalis effect

suggests myocardial ischemia

suggests ischemia/digitalis effect

may be due to myocardial ischemia

suggests possible myocardial ischemia/digitalis effect

is age and gender related

is age and gender related – possible digitalis effect

is consistent with myocardial ischemia

is consistent with ischemia/digitalis effect

- possible digitalis effect

is borderline

is borderline for age and gender

is borderline for age and gender – possible digitalis effect

is consistent with digitalis effect

is probably due to digitalis effect

suggests digitalis effect/ischemia

is nonspecific

is nonspecific

18.16 Miscellaneous –Low QRS Voltages

Low QRS voltages in limb leads

Low QRS voltages in precordial leads

Generalized low QRS voltages

Generalized low QRS voltages – consider pericardial effusion

18.17 Miscellaneous –Tall T Waves

Tall T waves - consider acute ischemia or hyperkalemia

Tall T waves - consider hyperkalemia

18.18 Critical Values

Consider Acute STEMI
Acute MI/Ischemia
Extreme Tachycardia
Extreme Bradycardia
Significant Arrhythmia
Prolonged QTc Interval

18.19 Dominant Rhythm Statements

Sinus rhythm
Sinus tachycardia
Sinus bradycardia
Sinus arrhythmia
Sinus tachycardia with sinus arrhythmia
Sinus bradycardia with sinus arrhythmia
Atrial tachycardia
Atrial flutter
Atrial fibrillation
Junctional rhythm
Accelerated junctional rhythm
Junctional bradycardia
Atrial pacing
Ventricular pacing
A-V sequential pacemaker
Pacemaker rhythm
Possible ectopic atrial rhythm
Possible ectopic atrial tachycardia
Possible ectopic atrial bradycardia
Irregular ectopic atrial rhythm
Irregular ectopic atrial tachycardia
Irregular ectopic atrial bradycardia
Probable atrial tachycardia
Probable sinus tachycardia
Probable supraventricular tachycardia
Marked sinus bradycardia
Probable atrial flutter
Probable atrial fibrillation
Probable junctional rhythm
Probable accelerated junctional rhythm
Probable ventricular tachycardia
Wide QRS tachycardia
Accelerated idioventricular rhythm

Possible idioventricular rhythm

Possible atrial flutter

Possible junctional rhythm

Possible accelerated junctional rhythm

Possible junctional bradycardia

A-V dissociation

Undetermined rhythm

Regular supraventricular rhythm

Irregular supraventricular rhythm

18.20 Supplementary Rhythm Statements

with frequent PVCs

with multifocal PVCs

with frequent multifocal PVCs

with interpolated PVC(s)

with multifocal interpolated PVCs

with PVC(s)

with PAC(s)

with frequent PACs

with aberrantly conducted supraventricular complexes

with 1st degree A-V block

with borderline 1st degree A-V block

with 2nd degree A-V block, Mobitz I (Wenckebach)

with 2nd degree A-V block, Mobitz II

with 2:1 A-V block

with 3:1 A-V block

with 4:1 A-V block

with high degree A-V block

with varying 2nd degree A-V block

with complete A-V block

with 2nd degree (Mobitz II) SA Block

with bigeminal PACs

with bigeminal PVCs

Demand atrial pacing

Demand pacing

with fusion complexes

with non-sustained ventricular tachycardia

with intermittent conduction defect

with paroxysmal idioventricular rhythm

with unclassified aberrant complexes

with undetermined ectopic complexes

with undetermined irregularity

or aberrant ventricular conduction

with rapid ventricular response

with uncontrolled ventricular response

with slow ventricular response

18.21 Summary Statements

Normal ECG

Normal ECG except for rate

Normal ECG except for rhythm

Normal ECG based on available leads

Borderline ECG

Abnormal ECG

Technical error

19 Accuracy of Contour Statements

19.1 CSE Evaluation

Tables 1 – 3, which follow this section, provide the results of analysing the 1220 ECGs in the Common Standards for Quantitative Electrocardiography (CSE) database using Version 28 of the Glasgow Program. The analysis was undertaken in July 2010. The following is a brief explanation of the study and the outputs.

The CSE database [15] 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/s 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 accuracy of software 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 59.8% 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 ischaemia, the corresponding ECG would be regarded as 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 27.1%.

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 [15] 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 an 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. 59.8% correct diagnoses of LVH vs. the clinical data and 73.7% vs. the cardiologists. Note also that in the group of 382 controls, the Glasgow program agreed in 98.4% of cases with the cardiologists.

In conclusion, it is pleasing to note that the total accuracy remains very high at 73.7%. This is particularly satisfying given the large number of changes which continue to be made to the program compared to the original program of 1991 when the total accuracy was 69.7%. Repeatability of interpretation is not assessed by the CSE test set nor is rhythm analysis or conduction defects. Nonetheless, the enhanced total accuracy is always to be welcomed! Accuracy with respect to the cardiologists continues to remain very high at 80.86%.

19.2 Databases

19.2.1 CSE (Common Standards for Quantitative Electrocardiography) Database

The CSE database [15] consisted of 1220 ECGs recorded from individuals living in several European countries. It included recordings from 831 men and 389 women, mean age 52 ± 13 years. The cohort consisted entirely of European subjects and although the racial distribution was never determined, it could be assumed to be 100% Caucasian. 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. Three cardiologists from different European countries reviewed the clinical data and agreed on the clinical classification.

There was a second classification produced by a set of 8 cardiologists, who each interpreted the 1220 ECGs. Their interpretations were combined to produce a so-called "cardiologist interpretation" or "combined referee" with respect to which programs, and the individual cardiologists themselves, were also evaluated.

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

19.2.2 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 989 were selected as a representative sample of a hospital population. 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 499 males (mean age 62 ± 22 years) and 490 females (mean age 68 ± 19 years) in the database with an age range of 3 days to 96 years. There were 74 subjects with an age of 16 years or under, or aged 17 or 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.

19.2.3 Glasgow Adult Normal Database

The normal ECG database was composed of ECGs recorded from 1498 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. This database has been used extensively in the determination of normal limits of ECGs such as those relating to the QT interval [14]. It contains ECGs from 863 males and 638 females with an age range of 18 to 78 years. This cohort was recruited from local government workers in Glasgow plus students from the University and was essentially 100% Caucasian.

19.2.4 Glasgow Pediatric ECG Database

This database of 809 ECGs was recorded from neonates, infants and children referred or admitted to hospital for investigation of various problems. There were 423 males (mean age 5.5 ± 5.1 years) and 383 females (mean age 5.6 ± 5.2 years) with a combined age range of 1 day to 18 years. The subject's sex 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 527 children whose ECGs were being reviewed. The remaining ECGs were reported without knowledge of the clinical history. Results using this database have now been published [16, 17].

19.2.5 Pacemaker ECG Database

The accuracy of statements relating to artificial implanted pacemaker rhythm is entirely dependent on the detection of the pacemaker stimuli. Thus, for this database, 45 ECGs were selected where the pacemaker stimuli were seen to be correctly detected from inspection of relevant indicators on the ECG printout. Age, sex and racial distribution are of no relevance.

19.2.6 Database of Additional Cases of Atrial Fibrillation

In order to supplement the number of cases of atrial fibrillation, an additional 71 cases were added to the database of ECGs from which rhythm analysis was assessed. There were 47 males (mean age 66.9 ± 15.4 years) and 24 females (mean age 74.3 ± 8.4 years).

19.2.7 Measurement database per IEC 60601-2-51

The International Electrotechnical Commission, or IEC, is a worldwide organization for standardization. International standard IEC 60601-2-51 has been prepared by an IEC subcommittee SC 62D, Electromedical equipment, of the IEC technical committee 62: Electrical equipment in medical practice.

The document IEC 60601-2-51 contains details of databases for automated measurements on ECGs including calibration and analytical ECGs, CSE biological ECGs and a subset of CSE ECGs for testing noise stability.

19.3 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.

19.4 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) = $\frac{TP}{(TP + FN)}$

SPECIFICITY (SPEC) = $\frac{TN}{(TN + FP)}$

POSITIVE PREDICTIVE VALUE (PPV) = $\frac{TP}{(TP + FP)}$

NEGATIVE PREDICTIVE VALUE (NPV) = $\frac{TN}{(TN + FN)}$

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

TOTAL ACCURACY = $\frac{\text{Total number of cases correctly classified}}{1220}$

19.5 CSE Abbreviations

NL	**=**	**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**

19.5.1 Results

Table 1 -- Results from an analysis of the CSE database in July 2010. In this case, the gold standard ("truth") was derived from the clinical data.

Type A Statements [1]

DIAGNOSTIC CATEGORY	SENSITIVITY	SPECIFICITY	PPV	NPV	PREVALENCE
NL	98%	76% [2]	65% [2]	99%	382/1220
LVH	60%	97%	81%	93%	183/1220
RVH	47%	100%	93%	98%	55/1220
BVH	48%	100%	81%	98%	53/1220
AMI	69%	99%	91%	95%	170/1220
IMI	70%	99%	94%	92%	273/1220
MIX	59%	99%	71%	97%	73/1220

Total Accuracy: 73.7% Partially correct: 75.4% (both on 1220 cases)

1 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.

2 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 2 -- Results from an analysis of the CSE database in July 2010. 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. 1.0% of ECGs from individuals regarded as normal were reported by the program as LVH. On the other hand, 29.5% of ECGs from patients with clinical evidence of LVH were reported as normal.

Type A Statements

PROG TRUTH	NL	LVH	RVH	BVH	AMI	IMI	MIX	VH+MI	OTHER	TOTAL	PREV
NL	**97.6**	1.0	0.0	0.0	1.0	0.3	0.0	0.0	0.0	100%	382/1220
LVH	29.5	**59.8**	0.5	2.2	2.7	4.6	0.5	0.0	0.0	100%	183/1220
RVH	38.2	9.1	**47.3**	1.8	0.0	1.8	0.0	0.0	1.8	100%	55/1220
BVH	11.3	0.0	0.0	**47.6**	6.1	1.9	0.9	0.0	30.7	100%	53/1220
AMI	17.1	5.6	0.0	0.6	**68.8**	0.9	7.1	0.0	0.0	100%	170/1220
IMI	27.1	1.3	0.4	0.0	0.0	**69.8**	1.5	0.0	0.0	100%	273/1220
MIX	10.3	6.2	0.0	0.0	0.0	0.0	**58.9**	0.0	24.7	100%	73/1220
VH+MI	29.0	0.0	0.0	0.0	0.0	0.0	0.0	**46.8**	24.2	100%	31/1220

Total accuracy: 73.7 % Partially correct: 75.4 % (both on 1220)

Table 3 -- Distributions of the CSE July 2010 computer interpretations with respect to the consensus opinion of the 8 cardiologists. Prevalence totals change compared to Tables 1 and 2 because the gold standard has changed.

Type A Statements

PROG REF	NL	LVH	RVH	BVH	AMI	IMI	MIX	VH+MI	OTHER	TOTAL	PREV
NL	**93.0**	2.5	0.8	0.5	0.7	1.1	0.1	0.1	1.2	100.0	503/1220
LVH	18.3	**73.7**		2.8		4.2	0.3		0.7	100.0	145/1220
RVH	26.7		**71.7**		1.7					100.0	30/1220
BVH	3.4	12.1	5.2	**69.0**	3.4				6.9	100.0	29/1220
AMI	11.6	3.8		1.3	**76.1**	0.6	6.6			100.0	159/1220
IMI	15.3	1.8	0.4	0.2		**81.8**	0.4			100.0	228/1220
MIX	12.5	2.1			2.8	4.9	**68.8**		9.0	100.0	72/1220
VH+MI	22.7	4.5				2.3		**59.1**	11.4	100.0	22/1220
OTHER	7.8	3.1		7.8	3.1		4.7	3.1	**70.3**	100.0	32/1220
TOTAL	47.0	11.1	2.3	2.6	10.6	16.7	5.2	1.2	3.3	100.0	1220

Total agreement 80.86%

Table 4 -- Results on type B statements. Data were obtained from the Glasgow validation ECG database from which 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 946 ECGs available for assessment of type B statements in adults.

Type B Statements – Conduction Defects

CONDUCTION DEFECT	SENS	SPEC	PPV	NPV	PREVALENCE
RBBB	88.00%	99.78%	91.67%	99.67%	25/946
LBBB	100.00%	100.00%	100.00%	100.00%	17/946
rSr' (V1) normal variant	100.00%	100.00%	100.00%	100.00%	17/946
IVCD	86.67%	99.25%	65.00%	99.78%	15/946
WPW	90.91%	100.00%	100.00%	99.67%	33/946
(Possible) LAFB	94.12%	99.45%	86.49%	99.78%	34/946

Where:

RBBB = Right bundle branch block

LBBB = Left bundle branch block

LAFB = Left anterior fascicular block

IVCD = Intra ventricular conduction defect

WPW = Wolf Parkinson White

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

Table 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 ECGs from apparently healthy adults was also incorporated to increase the number of sinus and other common rhythms. These ECGs were supplemented by 71 cases of atrial fibrillation that were included to augment the number of cases of this arrhythmia.

Type B Statements – Rhythm

DOMINANT RHYTHM STATEMENT	SENS	SPEC	PPV	NPV	PREV
Sinus rhythm	99.45%	97.61%	99.35%	97.97%	2012/2555
Sinus bradycardia	97.50%	99.96%	97.50%	99.96%	40/2555
Atrial fibrillation	88.81%	99.92%	98.45%	99.34%	143/2555
Sinus arrhythmia	95.95%	99.88%	97.93%	99.75%	148/2555
Sinus tachycardia	100.00%	99.88%	96.25%	100.00%	77/2555
Atrial flutter	87.80%	99.96%	97.30%	99.80%	41/2555
Possible atrial flutter	100.00%	99.88%	90.63%	100.00%	29/2555
Possible ectopic atrial rhythm	95.00%	99.80%	88.37%	99.92%	40/2555

Where an arrhythmia occurred in the database with a frequency < 10, 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 bradycardia with sinus arrhythmia
- 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
- Possible ectopic atrial bradycardia
- Wide QRS tachycardia
- Accelerated idioventricular rhythm

- Possible idioventricular rhythm
- Probable atrial flutter
- Undetermined rhythm
- Irregular supraventricular rhythm
- Probable ventricular tachycardia
- (Accelerated) junctional rhythm

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

SUPPLEMENTARY STATEMENT	SENS	SPEC	PPV	NPV	PREV
~ with rapid ventricular response	100.00%	99.92%	97.18%	100.00%	69/2555
~with PVCs	96.55%	99.72%	88.89%	99.92%	58/2555
~ with PACs	90.24%	99.36%	69.81%	99.84%	41/2555
~ with borderline 1st degree A-V block	97.06%	99.48%	83.54%	99.92%	68/2555
~ with 1st degree A-V block	89.47%	99.68%	80.95%	99.84%	38/2555
~ or aberrant ventricular conduction	83.33%	99.92%	88.24%	99.88%	18/2555

Where a supplementary rhythm statement occurred in the database with a frequency < 10, 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
- ~ with slow ventricular response

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 7 -- Data derived from 45 cases of paced ECGs

PACING STATEMENT	SENS	SPEC	PPV	NPV	PREV
Ventricular pacing	76.19%	100.00%	100.00%	82.76%	21/45
A-V Sequential Pacemaker	70.00%	100.00%	100.00%	92.11%	10/45

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

- Atrial Pacing
- Demand Atrial Pacing
- Demand Pacing

Table 8 -- Type C statements in adults derived from the Glasgow validation ECG database.

ECG FINDINGS	SENS	SPEC	PPV	NPV	PREV
LAD	91.67%	99.77%	96.49%	99.42%	60/915
Leftward axis	100.00%	100.00%	100.00%	100.00%	57/915
RAD	100.00%	100.00%	100.00%	100.00%	12/915
Rightward axis	100.00%	100.00%	100.00%	100.00%	13/915
Non specific ST-T changes	97.24%	99.05%	96.17%	99.32%	181/915
rSr' – probable normal variant	100.00%	100.00%	100.00%	100.00%	17/915
Poor R wave progression	84.38%	100.00%	100.00%	99.44%	32/915

Where:

LAD =Left axis deviation

RAD =Right axis deviation

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 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

ECG FINDINGS	SENS	SPEC	PPV	NPV	PREV
NL	93.37%	97.84%	97.60%	94.01%	392/809
RVH	74.14%	92.54%	55.13%	96.66%	58/527
LVH	38.71%	95.16%	33.33%	96.13%	31/527

Where:

RVH = Right ventricular hypertrophy

LVH = Left ventricular hypertrophy

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

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

Type B Abnormalities in Children

ECG FINDINGS	SENS	SPEC	PPV	NPV	PREV
RBBB	82.61%	99.48%	90.48%	98.96%	46/809
IVCD	90.91%	99.37%	66.67%	99.87%	11/809

Where:

RBBB = Right bundle branch block

IVCD = Intra ventricular conduction defect

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

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

Type C ECG Abnormalities in Children

ECG FINDINGS	SENS	SPEC	PPV	NPV	PREV
….ST-T changes are non specific	92.24%	98.99%	93.86%	98.71%	116/809
….ST elevation……	93.18%	99.87%	97.62%	99.61%	44/809
Rightward axis	100.00%	100.00%	100.00%	100.00%	62/809
Right axis deviation	100.00%	100.00%	100.00%	100.00%	35/809
Severe right axis deviation	100.00%	100.00%	100.00%	100.00%	10/809
QRS axis leftward for age	100.00%	99.87%	97.22%	100.00%	35/809
Left axis deviation	100.00%	100.00%	100.00%	100.00%	20/809

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

20 Measurement Accuracy

The IEC measurement database (see ***19.2.7 Measurement database per IEC 60601-2-51***) was used to test the accuracy of the program in measuring various wave amplitudes, durations and intervals. The program measurements were well within the acceptable IEC recommended tolerances for the calibration and analytical ECGs and CSE biological measurement ECGs. Table 12 below shows the disclosed changes of measurements caused by noise. The IEC document 60601-2-51 does not suggest acceptable mean differences and standard deviations, i.e. tolerances, for noise testing.

Table 12-- The mean differences and standard deviations between measurements made by the program on ECGs with various types of noise added and the same ECGs without noise added.

Global Measurement	Type of Added Noise	Disclosed Differences	
		Mean_Diff (ms)	Standard Deviation (ms)
P Duration	High Frequency	0.800	2.700
P Duration	Line Frequency (50 Hz)	0.000	1.333
P Duration	Line Frequency (60 Hz)	-2.200	5.692
P Duration	Base-Line	0.000	1.333
QRS Duration	High Frequency	0.600	3.534
QRS Duration	Line Frequency (50 Hz)	0.600	2.836
QRS Duration	Line Frequency (60 Hz)	-0.600	2.675
QRS Duration	Base-Line	0.000	3.127
QT Interval	High Frequency	-2.200	3.048
QT Interval	Line Frequency (50 Hz)	-0.200	0.632
QT Interval	Line Frequency (60 Hz)	-0.200	1.476
QT Interval	Base-Line	-0.800	1.398

FOR YOUR NOTES

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