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MEANS ECG Physicians' Manual for Norav Medical PC-ECG 1200 Electrocardiographs

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Federal US law restricts sale of the device identified in this manual to, or on the order of, a licensed physician.

About this manual

This manual documents the logic behind the diagnostic criteria provided by the Norav Medical PC-ECG 1200 interpretive resting ECG system. It is provided as a supplement to the electrocardiographs user's manual for those interested in or requiring knowledge of specific details of the system's algorithms. Please refer to the electrocardiographs general user's manual for information about use, installation and configuration, as well as applicable precautions and warnings.

The algorithms employed in our system are collectively known as the Modular ECG Analysis System, MEANS. MEANS was developed by the Department of Medical Informatics at the Erasmus University of Rotterdam in the Netherlands.

The initial sections of this manual provide an overview of the general signal processing methodology involved, followed by detailed descriptions of the contour and rhythm analysis statement logic, and an index to all statements. The final section provides an analysis of the performance of MEANS.

Contents

1 Introduction

Computers and humans interpret ECG signals in fundamentally different ways. The principal difference is in the manner in which a computer “looks at” the signal. To be interpretable, a continuous (analog) signal must be converted into numbers, i.e., digitized. The signals are measured at short intervals, and the measured values (the samples) are stored as digital numbers. On this set of numbers the analysis must take place. The sampling must be dense enough to ensure sufficient fidelity in rendering the original analog signal. Current standards for ECG recording recommend a sampling rate of 500 Hz or higher.

After collection of the data, the processing follows a number of successive stages:

- Signal conditioning
- Pattern recognition
- Parameter extraction
- Diagnostic classification

Each of these steps must be performed correctly to ensure a satisfactory final result. If, for instance, the signals are not correctly cured of disturbances this may result in a faulty waveform recognition. The diagnostic classification is then likely to come out wrong. The successive steps will now be discussed more extensively.

1.1 Signal conditioning

The ECG signal can be disturbed in several ways:

- Continuous noise of a single frequency, sometimes with higher harmonics, due to 50 or 60 Hz AC mains interference.
- Drift: more or less gradual baseline shifts, e.g., caused by respiration.
- Bursts of noise of mixed frequencies and various amplitudes due to electrical signals from active muscles.
- Sudden baseline jumps due to changes in electrode-skin impedance.
- Spikes: isolated, large amplitude variations of short duration.
- Amplitude saturation of the signal.

To correct these disturbances, several techniques have been used. Mains interference is suppressed by an adaptive filter that estimates the coming noise estimates and subtracts the estimates from the encountered signal. Baseline shift is corrected by simply connecting the onsets of successive QRS complexes by straight lines and determining the signal amplitudes with respect to these line segments. Beat selection and averaging (see below) help to reduce disturbances of muscle noise. If a disturbance is detected that may affect the diagnostic classification, the program issues a warning.

1.2 Pattern recognition

This part deals with the analysis of the various waveforms. First of all, the QRS complexes must be *detected*. No other waves or artifacts should be labeled as such. The intervals between QRS complexes are measured and stored. After all QRS complexes have been detected, they are *typified*, i.e., a comparison is performed that gives rise to classes of similar QRS complexes.

Often there is only one type of QRS complex. If there are more, the “ordinary,” “representative” or “dominant” one is established; the others are “extraordinary” or “non-dominant”. Mostly, the number of dominant complexes in a recording is larger than that of the non-dominant ones. In special cases this may not be true. In bigeminy their number may be equal to that of the non-dominant complexes, or be one less or one more, depending on when the recording starts and stops. If runs of tachycardia occur, the unusual complexes in a recording may even outnumber the dominant ones.

The second step is to search for atrial activity. Both P waves and flutter waves can be detected, when present. PP and PR intervals are also measured and stored for use in the rhythm analysis.

The third step is to mutually compare the ST-T segments of the dominant complexes. For the calculation of the averaged complex, only complexes are selected that have not only similar QRS, but also similar ST-T. In this way complexes that are disturbed by spikes or sudden baseline jumps are discarded.

For the morphological analysis, the selected dominant P-QRS-T complexes are averaged into one complex. The main advantage of averaging is to improve the signal-to-noise ratio. Noise is random and, in the averaging, the positive and negative oscillations will cancel out. An additional advantage is that the analysis now has to be performed only once, i.e., on a single representative complex. It may occur that in the averaged complex a P wave appears which was not consistently detectable in the rhythm analysis, or vice versa.

The final step in the pattern recognition process is the determination of the zero level in the representative P-QRS-T complex and the identification of the points of onset and offset of P, QRS, and T. The zero level is determined for the averaged complex per lead in an interval preceding the onset of the QRS complex. Onsets and offsets however are determined simultaneously over all leads together.

1.3 Parameter extraction

After the onset and end points of P, QRS and T waves have been established, the relevant parameters can be measured to provide the input for the diagnostic logic. Besides amplitudes and durations, other measurements such as surface areas under the signal are derived. Most measurements are made on the averaged complex in each lead separately (e.g., R amplitude, Q duration), but some are derived taking all leads into account (e.g., overall QRS duration, PR interval). These durations are generally longer than one would measure by hand in individual leads or lead groups since the first onset in any lead and the last offset are taken into account.

1.4 Diagnostic classification

The diagnostic logic operates on the parameters and produces both a rhythm classification and a contour or morphology classification. The criteria used by the computer may differ from the criteria used in the ECG textbooks. The basic reason is that a human observer is inaccurate but flexible and creative, a computer precise and obedient but rigid in its operation.

There are several specific reasons why ECG criteria in the program may differ from the conventional ones. First, there is no uniformity of criteria in the literature. Then, criteria may be based on inaccurate measurement by eye. Also, ECG measurements may be "falsified" for the ease of the reader: axis calculations are generally made from the amplitudes of QRS complexes rather than from the surface areas under the QRS tracings as prescribed by theory. Further, criteria are sometimes not quantitatively defined (How flat must a flat ST-T be? How slurred is a slurred QRS upstroke?) or their measurement is not unequivocally prescribed. For the computer program to work, a quantitative definition must somehow be decided upon. Moreover, conventional criteria may have been based on measurements produced by technically outdated instrumentation. The amplitudes of R waves have been consistently underestimated, especially in children, due to filtering effects by too low frequency response of the electrocardiographs. Finally, a human interpreter may deviate from strict criteria as he sees fit: sometimes criteria have been made to meet a priori expectations.

In one respect, the computer is inferior to the human observer: although the computer can measure very accurately, its powers of pattern recognition are inferior. For instance, it will have great trouble in detecting a P wave buried in a ST segment which is easily seen by the human eye.

1.5 Outline of the manual

The following of this manual consists of two main parts. One part describes the diagnostic criteria that are employed in the contour classification of the Modular ECG Analysis System (MEANS), the other describes the criteria used in the rhythm classification of MEANS. Each part contains a brief introductory section, a description of the measurements that are used in the diagnostic logic, and a comprehensive list of statements and corresponding diagnostic criteria. Related statements have been grouped in sections, e.g., all statements related to intraventricular conduction delay, left ventricular hypertrophy, etc. Finally, an index of the statements that can be generated by the program is provided on page 55.

A general format is used to specify the diagnostic criteria. The statement is given first, followed by one or more conditions that must be fulfilled for the statement to be issued by the program. Multiple conditions are combined with the use of logical "and" and "or" connectives, binding the (combinations of) conditions that have the same level of indentation. For example:

Say:	"probable inferior infarct"
if:	Q duration $\geq$ 40 ms and 0.2 $\leq$ Q/R ratio < 0.3 in aVF
or	30 $\leq$ Q duration < 40 ms and Q/R ratio $\geq$ 0.3 in aVF
or	Q duration in aVF $\geq$ 20 ms
and	Q duration $\geq$ 50 ms and Q amplitude > 300 µV in III

1.6 References

In several publications, the program structure and signal analysis part of MEANS have been described. One publication, which also provides many references for further reading, is:

- Van Bemmel JH, Kors JA, Van Herpen G. Methodology of the modular ECG analysis system MEANS. Methods Inf Med 1990;29:346-53.

The measurement and classification parts of MEANS have extensively been evaluated, both by the developers themselves and by independent observers. A major evaluation study in the field of automated electrocardiography has been the project *Common Standards for Quantitative Electrocardiology* (CSE), in which about 15 ECG computer programs from all over the world have participated. The CSE study consisted of two parts, one pertaining to the measurement part of the ECG programs, the other to the diagnostic classification part. Two key references are:

- Willems JL, Arnaud P, Van Bemmel JH, Bourdillon PJ, Degani R, Denis B, et al. A reference database for multi-lead electrocardiographic computer measurement programs. J Am Coll Cardiol 1987;10:1313-21.

- Willems JL, Abreu-Lima C, Arnaud P, Van Bemmel JH, Brohet C, Degani R, et al. The diagnostic performance of computer programs for the interpretation of electrocardiograms. N Engl J Med 1991;325:1767-73.

2 Contour analysis

2.1 Contour parameters

All parameters that are used in the diagnostic criteria of the contour classification are measured in the representative P-QRS-T complex. The lead-independent, overall parameters are presented in Table 1.

Table 1. Lead-independent parameters for the contour classification.

Name	Description
Heart rate	Ventricular rate (in beats per minute, BPM)
P axis	Axis of the P wave (in degrees, from –180 to 180)
P duration	Duration of the P wave (in ms)
PR interval	Duration of the PR interval (in ms)
QRS axis	Axis of the QRS complex (in degrees, from –180 to 180)
QRS duration	Duration of the QRS complex (in ms)
Corrected QT interval	QT interval corrected for heart rate according to Bazett's formula: $QTc = QT * \sqrt{(HR/60)}$ (in ms) Hodges' formula: $QTc = QT + 1.75 \times (HR-60)$ Note: The CP 100 and CP 200 devices support either the Bazett or Hodges QTc calculation on the printout. MEANS always uses the Bazett calculation in its interpretive output statements.

The parameters that are computed for each lead separately, are shown in Table 2. All amplitudes are taken as absolute values.

Table 2. Lead-dependent parameters for the contour classification.

Name	Description
Delta wave	Slurring of the initial part of the QRS complex.
Negative J amplitude	Amplitude of a negative J point (in µV).
Positive J amplitude	Amplitude of a positive J point (in µV).
Negative P amplitude	Amplitude of the negative deflection of the P wave (in µV).
Positive P amplitude	Amplitude of the positive deflection of the P wave (in µV).
P notch	Notch in the positive deflection of the P wave.
Q amplitude	Maximum amplitude of the Q wave (in µV).
Q duration	Duration of the Q wave (in ms).
negative QRS amplitude	Amplitude of the largest negative deflection of the QRS complex (in µV).
positive QRS amplitude	Amplitude of the largest positive deflection of the QRS complex (in µV).
top-top QRS amplitude	Amplitude of largest positive plus largest negative deflections of the QRS complex (in µV).
QRS area	Area under the positive deflections of the QRS complex minus area under the negative deflections of the QRS complex (in mVms).
Q/R ratio	Ratio of the maximum amplitudes of the Q and R waves.
QS pattern	QRS complex consisting of a Q wave only.
R amplitude	Maximum amplitude of the R wave (in µV).
R duration	Duration of the R wave (in ms).
R notch	Notch in the positive deflection of the QRS complex.
R′ amplitude	Maximum amplitude of the R′ wave (in µV).
R/S ratio	Ratio of the maximum amplitudes of the R and S waves.
S amplitude	Maximum amplitude of the S wave (in µV).
S duration	Duration of the S wave (in ms).
S′ amplitude	Maximum amplitude of the S′ wave (in µV).
ST slope	Slope of the ST segment (in µV/100 ms).
Negative T amplitude	Amplitude of the negative deflection of the T wave (in µV).
Positive T amplitude	Amplitude of the positive deflection of the T wave (in µV).

2.2 Dextrocardia and arm electrodes reversal

Skip tests
if: QRS area in I > 0
or top-top QRS amplitude in I ≤ 150 µV
or positive T wave in I
or −100 ≤ P axis ≤ 100°

Say: “dextrocardia”
if: top-top QRS amplitude in V6 ≤ 500 µV

Say: “arm electrodes interchanged”
if: top-top QRS amplitude in V6 > 500 µV

If either test passed, no further contour analysis is performed.

2.3 Wolf-Parkinson-White syndrome (WPW)

The presence of delta waves is a necessary condition for the diagnosis of WPW. The length of the PR interval is another obvious parameter to use. However, it is not a necessary criterion, for if the accessory pathway is slowly conducting, the PR interval could be normal. Moreover, WPW can occur in the absence of P waves, for example in the presence of atrial fibrillation. For this reason this criterion has not been used to construct the diagnosis of WPW, but has only to distinguish between LBBB and WPW type B in case both diagnoses have been made (see section LBBB).

Say: “WPW”
if: delta waves in at least 2 extremity leads
and delta waves in at least 2 precordial leads
and QRS duration > 100 ms

If test WPW passed, only a test for LBBB is performed.

2.4 Left Bundle Branch Block (LBBB)

The primary condition for the diagnosis of a complete block is prolonged QRS duration. In the program the limit is 130 ms. The normal initial QRS activity to the right and anterior is smaller than normal or absent. Soon after the beginning of QRS the electrical forces turn posteriorly, and somewhat to the left and mostly horizontally. The predominantly posterior activity produces generally deep S waves in V1 and V2 while the R waves in V5 and V6 tend to remain low. Therefore, the program requires r waves in V1 and V2 to be minor (they even may be lacking, and in V5 and V6 q's must be reciprocally absent). This is expressed by the requirement of a net negative area and R/S ratio of less than 1/3 in V1. The R waves in V5 and V6 will have a delayed intrinsicoid deflection. Septal infarction should not be diagnosed in the presence of LBBB. Finally, if LBBB and WPW both come into consideration the case is decided by the duration of the PR interval.

Skip tests
if: Q wave in any of I, V5, V6
or QRS duration ≤ 130 ms

Say: "LBBB"
if: QRS area in V1 < −100 mVms
and S amplitude in V6 ≤ 1000 µV
or −100 ≤ QRS area in V1 < −40 mVms
and negative QRS amplitude > 3 times positive QRS amplitude in V1
and QRS area > 0 in V6
and intrinsicoid deflection at ≥ 50 ms in V5 or V6

Say: "possible LBBB"
if: QRS area in V1 < −100 mVms
and S amplitude in V6 > 1000 µV
or −100 ≤ QRS area in V1 < −40 mVms
and negative QRS amplitude > 3 times positive QRS amplitude in V1
and QRS area > 0 in V6
and intrinsicoid deflection at < 50 ms in V5 and V6
or QRS area ≤ 0 in V6
and intrinsicoid deflection at ≥ 50 ms in V5 or V6

if: test LBBB passed
and test WPW passed
and QRS area in V1 ≤ −5 mVms
and 0 ≤ QRS axis ≤ 90°
then:
Say: "possible LBBB"
"possible WPW"
if: PR interval > 140 ms

suppress: "LBBB"
if: PR interval ≤ 140 ms

2.5 Right Bundle Branch Block (RBBB)

The ECG abnormality in RBBB consists of a late, protracted QRS activity to the right and anterior with concomitant overall increase of QRS duration (≥ 130 ms). The program therefore looks for a late R, an R′ or a broad notched R wave in V1 or V2, all with delayed intrinsicoid deflection, and reciprocal broad S waves in the lateral leads.

The QRS axis has a certain influence on the S duration in lead I. Lead I, although horizontal in geometrical space, is tilted upward on the left side in electrical space. In left axis deviation, this will result in a projected S wave which is less deep and of shorter duration than the S wave in V5 or V6 leads that are tilted downwards on the left. This aspect has been taken into account for the criteria on the S duration. In the presence of RBBB, a diagnosis of RVH may also be entertained if the R wave in V1 is tall.

Skip tests
if: QRS duration < 130 ms
or S′ amplitude in V1 ≥ 100 µV

Say: “RBBB”
if: S duration ≥ 50 ms in I, V5, V6
and intrinsicoid deflection at ≥ 55 ms in V1 or V2
or S duration ≥ 30 ms in V5 or V6
and S duration in I ≥ 20 ms and QRS axis < –45°
or S duration in I ≥ 30 ms and QRS axis ≥ 45°
and R′ wave or R notch in V1 or V2
or Q wave and intrinsicoid deflection at ≥ 50 ms in V1

if: test RBBB passed
and Q amplitude > 100 µV in V1 and V2
then:
Say: “septal infarct”
if: Q duration ≥ 30 ms in V1 or V2

Say: “probable septal infarct”
if: Q duration ≥ 20 ms in V1 or V2

Suppress “RBBB”
if: Q amplitude in V2 ≤ 100 µV
or R amplitude in V2 < 200 µV
or intrinsicoid deflection in V2 at < 50 ms

if: test RBBB passed
then:
Say: “posterior infarct”
if: positive QRS amplitude in V1 ≥ 1500 µV
and positive T amplitude in V1 ≥ 700 µV

2.6 Incomplete Right Bundle Branch Block (IRBBB)

For IRBBB, comparable conditions apply the same as RBBB, but QRS duration is less increased (between 110 and 130 ms) and the intrinsicoid deflection time is shorter.

Skip tests
if: QRS duration ≥ 130 ms
or QRS duration ≤ 110 ms
or S′ amplitude in V1 ≥ 100 µV

Say: "incomplete RBBB"
if: R′ amplitude ≥ 300 µV in V1 or V2
or R′ in V1
and positive P wave in V1
or S duration ≥ 40 ms in I, V5, V6
and intrinsicoid deflection at ≥ 45 ms in V1 or V2

2.7 Intraventricular conduction delay (IVCD)

Only in the absence of diagnosable RBBB, LBBB or WPW will a statement of intraventricular conduction delay be made. The delay can be classified in different grades of severity.

Say: "slight intraventricular conduction delay
if: 112 ms ≤ QRS duration < 126 ms

Say: "moderate intraventricular conduction delay"
if: 126 ms ≤ QRS duration < 140 ms

Say: "marked intraventricular conduction delay"
if: 140 ms ≤ QRS duration < 180 ms

Say: "very marked intraventricular conduction delay"
if: QRS duration ≥ 180 ms

2.8 Atrial overload

The diagnosis of right or left atrial overload (RAO and LAO) will be considered in the presence of a normal P axis. Otherwise an unusual P axis will be reported.

In LAO the P wave is characterized by a broad negative terminal part in lead V1 and an increase of overall duration. In RAO a tall P wave in lead II and aVF and/or in V1 and V2 is expected. In diagnosing RAO an adjustment has been built in for heart rate: in tachycardia the amplitude of the P wave has to be slightly higher to qualify for the diagnosis, than with normal heart rate. The reason for this adjustment is the superposition of the P on the preceding U wave or T wave occurring at higher heart rates. Above 130 BPM no attempt is made to diagnose RAO.

Skip tests
if: P axis ≤ –30°
or P axis > 100°

Say: “left atrial overload”
if: negative P amplitude in V1 ≥ 180 µV
and P duration > 135 ms
or LVH test passed

Say: “right atrial overload”
if: heart rate < 100 BPM
and positive P amplitude ≥ 275 µV in V1 or V2
or positive P amplitude in II + positive P amplitude in aVF ≥ 525 µV
or 100 ≤ heart rate < 130 BPM
and positive P amplitude ≥ 300 µV in V1 or V2
or positive P amplitude in II + positive P amplitude in aVF ≥ 575 µV

2.9 Atrial abnormalities

Say: “unusual P axis”
if: P axis ≤ –30°
or P axis > 100°

Say: “intra-atrial conduction delay”
if: P duration > 135 ms
and negative P amplitude in V1 ≤ 180 µV

Say: “high P voltage”
if: test RAO did not pass
and positive P amplitude ≥ 275 µV in any lead
and heart rate < 100 BPM
or positive P amplitude ≥ 300 µV in any lead
and 100 ≤ heart rate < 130 BPM

2.10 Axis deviations and fascicular blocks

Axis deviations are distinguished in vertical, right, marked right and extreme right inferior on the one hand and horizontal, left, marked left and extreme right superior on the other hand.

Besides a complete LBBB it is also possible to find a left anterior or posterior fascicular block (LAFB or LPFB). These statements will always be tested in combination with an axis deviation. (LPFB can only be diagnosed in conjunction with RBBB.)

In the presence of inferior infarction no statement of left axis deviation is given, it being due to initial negativity in the inferior leads. In the presence of LBBB the axis tends to deviate to the left. Therefore the threshold for stating left axis deviation is increased. Moreover, the diagnosis of complete LBBB takes precedence over that of left anterior fascicular block.

Say: “vertical axis”
if: $80 < \text{QRS axis} \leq 100°$

Say: “right axis deviation”
if: $100 < \text{QRS axis} \leq 120°$

Say: “marked right axis deviation”
if: $120 < \text{QRS axis} \leq 150°$

Say: “extreme right inferior axis deviation”
if: $150 < \text{QRS axis} \leq 180°$

Say: “consistent with LPFB”
if: $120 < \text{QRS axis} \leq 180°$
and RBBB

Say: “horizontal axis”
if: $-30 \leq \text{QRS axis} < -10°$

if: test LBBB did not pass
then:
- Say: “left axis deviation”
  if: $-60 \leq \text{QRS axis} < -30°$
- Say: “marked left axis deviation”
  if: $-120 \leq \text{QRS axis} < -60°$
- Say: “extreme right superior axis deviation”
  if: $-180 \leq \text{QRS axis} < -120°$
- Say: “consistent with LAFB”
  if: $-120 \leq \text{QRS axis} < -45°$
  and S amplitude in III > 500 µV
  and S amplitude in III < S amplitude in II

if: test LBBB passed
then:
- Say: “left axis deviation”
  if: $-120 \leq \text{QRS axis} < -45°$

2.11 Low QRS voltage

Say: "low QRS voltage in extremity leads"
if: top-top QRS amplitude ≤ 500 µV in all extremity leads

Say: "low QRS voltage in precordial leads"
if: top-top QRS amplitude ≤ 1000 µV in all precordial leads

Say: "low QRS voltage"
if: both previous tests passed

2.12 QT abnormalities

The QT interval is measured from the beginning of the Q wave until the end of the T wave. In the case of intraventricular conduction delay, the excess QRS duration (>106 ms) is subtracted from the measured QT. A correction is made for the heart rate, using Bazett's equation: corrected QT interval = QT interval * √(heart rate/60). The corrected QT interval renders the QT interval for a standard heart rate of 60 beats per minute. The upper limit of 470 ms is increased to 500 ms in case of infarct.

Skip tests
if: WPWB and QRS duration < 126 ms
or heart rate ≥ 110 BPM

Say: "short QT interval, consider hypercalcaemia"
if: corrected QT interval < 330 ms

Say: "long QT interval, consider hypocalcaemia or quinidine-like drug"
if: corrected QT interval ≥ 470 ms
and no infarct test passed
or corrected QT interval ≥ 500 ms
and any infarct test passed

2.13 Left ventricular hypertrophy (LVH)

The diagnosis of LVH rests on three types of parameters: voltage, shape, and repolarization. For each parameter, points are accumulated according to its degree of abnormality. The higher the score, the higher the overall grading of the LVH. The following gradations are distinguished, in which severity and probability go together: “consider”, “possible”, “probable”, “definite”, “pronounced”, and “very pronounced”.

The *voltage* is determined in both the horizontal and frontal planes, but only the plane with the highest score will be used in the classification. For the horizontal plane the voltages are measured in leads V1, V5 and V6. In the frontal plane leads I and II are used. If the voltage in either plane does not meet the criteria, no further analysis for diagnosing LVH will be done.

In both planes an adjustment has been made for age. At age 35 no correction is applied, at age 90 a maximal correction of about 6 mm in the precordial measurement and of 3 mm in the frontal plane is added to the measured voltage. For people younger than 35 years the adjusted voltage will be lower than the calculated voltage, for older people the opposite applies.

The *shape* of the QRS complex is determined in that plane where the highest voltage score is reached. The main parameters on which the shape score is based are the intrinsicoid deflection and the sequence of small r waves in the right and tall R waves in the left precordial leads.

In the category *repolarization* the program tests for the presence and degree of ST depression and T negativity in the leads I, II, aVL, aVF, V5, and V6. Strain scores in the frontal and horizontal planes are determined using the ST slope and the J- and T-wave amplitudes.

2.14 Right ventricular hypertrophy

The diagnosis RVH is not subdivided in such an elaborate way as LVH is. A distinction between probable and definite can be made.

Presence of left or right atrial overload helps to make the diagnosis of RVH, because it provides circumstantial evidence. In the presence of RBBB, IRBBB or posterior infarction, the program may issue a statement that RVH is still to be considered. A more definite statement of RVH is ruled out, to prevent too much over-diagnosing.

Skip tests
if: QRS duration ≥ 160 ms
or QRS axis ≤ 0°
or test RBBB passed
or test LBBB passed

Say: "RVH"
if: R/S ratio ≥ 1 in V1 and Q/R ratio ≤ 1 in V1
and positive QRS amplitude in V1 ≥ 500 µV
and positive T amplitude < negative T amplitude in V1 and V2
or positive QRS amplitude < S amplitude in V5 or V6
or QRS axis ≥ 100°
and LAO or RAO
or QRS axis ≥ 120°
and R amplitude < S amplitude in II
and S amplitude in aVF ≤ 200 µV
and S duration in aVF < 40 ms
and tests for high-lateral, lateral, and inferior infarcts did not pass

Say: "probable RVH"
if: Q/R ratio ≤ 1 and R/S ratio ≥ 1 in V1
and positive QRS amplitude in V1 ≥ 1500 µV
and positive T amplitude in V1 < 700 µV
or Q/R ratio ≤ 1/2 and R/S ratio ≥ 2 in V1
and positive QRS amplitude in V1 ≥ 300 µV
and positive T amplitude < negative T amplitude in V1
or positive QRS amplitude < S amplitude in V5 or V6
or QRS axis ≥ 80°
and positive T amplitude < negative T amplitude in V1 and V2
and positive QRS amplitude < S amplitude in V5 or V6
and S amplitude in aVF ≤ 200 µV
and S duration in aVF < 40 ms
and test for lateral infarct did not pass
or QRS axis ≥ 100°
and LAO or RAO

Say: "consider RVH"
if: test RBBB passed
and QRS axis ≥ -45°
and positive T amplitude < negative T amplitude in V2
or test IRBBB passed
and positive QRS amplitude in V1 ≥ 500 µV
and positive QRS amplitude > negative QRS amplitude in V1
or test posterior infarct passed
and QRS axis > 100°

2.15 Infarction

This section of the program classifies an infarction according to location and estimates the probability of its presence. The diagnosis of infarction is largely based on the presence and duration of Q waves, Q/R ratios, and QS patterns. T and ST abnormalities are used in statements on the age of the infarct (see section Repolarization).

The location of the infarction is determined by the leads in which the abnormalities are found. The program distinguishes six locations: septal (lead V1, V2), anterior (V3, V4), lateral (V5, V6), high lateral (I, aVL), inferior (aVF, III), and posterior (V1, V2). Lead II may be involved in inferior infarction as well as in lateral infarction. Combined and more extensive infarcts will generate infarct statements for more than one location (see section Combination of statements).

Four degrees of probability are distinguished: “definite”, “probable”, “possible”, or “consider”.

Criteria on which a diagnosis of infarction has been made can also lead to other diagnoses, like LBBB, RBBB, LVH and RVH. The choice between these possible diagnoses is based on exclusion logic in the program, and in some situations, probabilities are adapted or criteria are tightened.

Inferior infarction

An abnormal Q wave must be found in aVF and either II or III to even consider the diagnosis of inferior infarction. As a rule the Q wave in aVF is shallower and shorter than that in III. Its threshold to qualify as an infarct Q can therefore be lower.

Inferior infarction may produce a left (i.e., superior) axis deviation if one only considers the ratio of upward and downward forces. In inferior myocardial infarction, however, this ratio is shifted due to initial negativity (Q in aVF) whereas in ordinary left axis deviation it is associated with deepening of the S wave in aVF.

Skip tests
if: Q amplitude + R amplitude in aVF < 200 µV
or Q amplitude in aVF ≤ 100 µV
or Q amplitude in II ≤ 70 µV
and Q amplitude in aVF ≤ 70 µV
or Q amplitude in III ≤ 100 µV

Say: “inferior infarct”
if: Q duration ≥ 40 ms and Q/R ratio ≥ 0.3 in aVF

Say: “probable inferior infarct”
if: Q duration ≥ 40 ms and 0.2 ≤ Q/R ratio < 0.3 in aVF
or 30 ≤ Q duration < 40 ms and Q/R ratio ≥ 0.3 in aVF
or Q duration in aVF ≥ 20 ms
and Q duration ≥ 50 ms and Q amplitude > 300 µV in III

Say: “possible inferior infarct”
if: 30 ≤ Q duration < 40 ms and 0.2 ≤ Q/R ratio < 0.3 in aVF
or 20 ≤ Q duration < 30 ms and Q/R ratio ≥ 0.3 in aVF
and Q duration in III ≥ 40 ms
or Q duration in aVF ≥ 20 ms
and 40 ≤ Q duration < 50 ms and Q amplitude > 300 µV in III

Septal infarction

Say: “septal infarct”
if: Q duration ≥ 35 ms and Q/R ratio ≥ 1/3 in V1 or V2
or Q duration ≥ 40 ms and Q amplitude > 100 μV in V1 or V2
or QS pattern in V2
and R amplitude in V1 ≥ 70 μV
or QS pattern in V3
or Q duration in V3 ≥ 25 ms
or Q wave and R amplitude < 250 μV and R duration < 26 ms in V3
or R amplitude < 200 μV and R duration < 16 ms in V3

Say: “probable septal infarct”
if: 25 ≤ Q duration < 35 ms and Q/R ratio ≥ 1/3 in V2 or V3
or 35 ≤ Q duration < 40 ms and 1/4 ≤ Q/R ratio < 1/3 in V2 or V3
or Q duration ≥ 30 ms and R amplitude ≥ 200 μV in V2
or R amplitude in V2 < 150 μV
and R amplitude in V2 < R amplitude in V1 − 50 μV
and R duration in V2 ≤ R duration in V1
or Q duration in V3 ≥ 25 ms

Say: “possible septal infarct”
if: 25 ≤ Q duration < 35 ms and 1/4 ≤ Q/R ratio < 1/3 in V1 or V2
or QS pattern and R amplitude < 70 μV in V1
and QS pattern in V2
and test LVH did not pass
or QS pattern or R amplitude < 70 μV in V1
and Q amplitude < S amplitude and R amplitude < S amplitude in V2
and test LVH did not pass

Anterior infarction

Say: “anterior infarct”
if: Q duration ≥ 35 ms and Q/R ratio ≥ 1/3 in V3 or V4
or Q duration ≥ 40 ms and Q amplitude > 100 μV in V3 or V4
or QS pattern in V3 or V4
or R amplitude < 100 μV in V3 and V4
or R amplitude < 100 μV in V4 and V5
or R amplitude < 150 μV in V2 and V3
and R amplitude < 150 μV or Q wave in V4
or R amplitude < 150 μV in V3 and V4
and R amplitude < 150 μV or Q wave in V5
or R amplitude in V3 < R amplitude in V2
and R amplitude in V3 < 150 μV
and R amplitude in V3 > R amplitude in V4 or Q wave in V4
or R amplitude in V4 < R amplitude in V3
and R amplitude in V4 < 150 μV
and R amplitude in V4 > R amplitude in V5 or Q wave in V5

Say: “probable anterior infarct”
if: 25 ≤ Q duration < 35 ms and Q/R ratio ≥ 1/3 in V3 or V4
or 35 ≤ Q duration < 40 ms and 1/4 ≤ Q/R ratio < 1/3 in V4 or V5
or R amplitude in V3 < 150 μV
and R amplitude in V3 < R amplitude in V2 − 50 μV
and R duration in V3 ≤ R duration in V2
or R amplitude in V4 < 150 μV
and R amplitude in V4 < R amplitude in V3 − 50 μV
and R duration in V4 ≤ R duration in V3

Say: “possible anterior infarct”
if: 25 ≤ Q duration < 35 ms and 1/4 ≤ Q/R ratio < 1/3 in V3 or V4

Lateral infarction

Say: “lateral infarct”
if: Q duration ≥ 35 ms and Q/R ratio ≥ 1/3 in V5 or V6
or Q duration ≥ 40 ms and Q amplitude > 100 μV in V5 or V6
or QS pattern in V5 or V6
or R amplitude < 100 μV in V5 and V6
or R amplitude < 150 μV in V4 and V5
and R amplitude < 150 μV or Q wave in V6
or R amplitude in V5 < R amplitude in V4
and R amplitude in V5 < 150 μV
and R amplitude in V5 > R amplitude in V6 or Q wave in V6

Say: “probable lateral infarct”
if: 35 ≤ Q duration < 40 ms and 1/4 ≤ Q/R ratio < 1/3 in V5 or V6
or Q duration < 35 ms and Q/R ratio ≥ 1/3 in V5 or V6
and R amplitude in V5 < R amplitude in V4 − 50 μV
or R amplitude in V6 < 150 μV
and R amplitude in V6 < R amplitude in V5 − 50 μV
and test RBBB did not pass
and test RVH did not pass

Say: “possible lateral infarct”
if: 25 ≤ Q duration < 35 ms and 1/4 ≤ Q/R ratio < 1/3 in V5 or V6

High-lateral infarction

An abnormal Q wave in both leads I and aVL is necessary to diagnose high-lateral infarction. In this situation the Q wave in I is by nature shallower and shorter than that in aVL. Therefore the threshold to qualify as an infarct Q is lower in I than in aVL.

A minimum amplitude condition has been built in for the R wave in lead I to prevent the diagnosis of a high-lateral infarction in pulmonary disease, where a very low R voltage in I may occur.

Skip tests
if: Q amplitude in I ≤ 70 µV
or Q amplitude in aVL ≤ 100 µV
or R amplitude in I < 100 µV

Say: "high-lateral infarct"
if: Q duration ≥ 40 ms in I and aVL
or 35 ≤ Q duration in I < 40 ms
and Q duration in aVL ≥ Q duration in I
and Q/R ratio ≥ 1/3 in I
or QRS axis ≥ 70°

Say: "probable high-lateral infarct"
if: 35 ≤ Q duration < 40 ms and 1/4 ≤ Q/R ratio < 1/3 in I
and Q duration in aVL ≥ Q duration in I
or 25 ≤ Q duration in I < 35 ms
and Q duration in aVL ≥ Q duration in I
and Q/R ratio ≥ 1/3 in I
or QRS axis ≥ 70°
or Q duration ≥ 20 ms and R amplitude ≥ 100 µV in I
and Q duration ≥ 50 ms and R amplitude ≥ 300 µV in aVL

Say: "possible high-lateral infarct"
if: 25 ≤ Q duration < 35 ms and 1/4 ≤ Q/R ratio < 1/3 in I
and Q duration in aVL ≥ Q duration in I
or Q duration ≥ 20 ms and R amplitude ≥ 100 µV in I
and 40 ≤ Q duration < 50 ms and R amplitude ≥ 300 µV in aVL

Posterior infarction

Skip tests
if: test RBBB passed
or test IRBBB passed

Say: “possible posterior infarct”
if: test RVH did not pass
and R amplitude ≥ 300 µV and R duration ≥ 30 ms in V1
and R amplitude ≥ 700 µV and R duration ≥ 40 ms in V2
and no Q wave in V2
and R/S ratio in V2 ≥ 1
and positive T amplitude ≥ negative T amplitude in V1 and V2
or negative J amplitude > 100 µV and positive T amplitude ≥ 100 µV in V2
and test inferior infarct passed
or Q amplitude > 100 µV and R amplitude < 1500 µV and Q/R rat ≥ 0.2 in V6
or
test RVH passed
and test inferior infarct passed

2.16 Pulmonary disease

Skip tests
if: QRS duration ≥ 126 ms
or positive QRS amplitude in V5 ≥ 950 µV
or test septal infarct passed
or test anterior infarct passed
or test lateral infarct passed

Say: "consider pulmonary disease"
if: undetermined P axis
and QRS area in V5 < 0
and top-top QRS amplitude ≤ 500 µV in all extremity leads
or 80 ≤ QRS axis < 120°
or 50 ≤ P axis < 110°
and QRS area in V4 < 0
and top-top QRS amplitude ≤ 500 µV in all extremity leads
or 80 ≤ QRS axis < 120°
or RAO
or QRS area in V3 < 0 and positive P amplitude in II ≥ 250 µV
or top-top QRS amplitude ≤ 500 µV in all extremity leads
and QRS area in V4 < 0
and top-top QRS amplitude in V6 < 600 µV
and 80 ≤ QRS axis < 120°
or RAO
or QRS area in V3 < 0 and positive P amplitude in II ≥ 250 µV

Say: " with cor pulmonale"
if: test pulmonary disease passed
and Q amplitude in V1 ≤ 70 µV
and R amplitude in V1 ≥ 60 µV
and R′ amplitude in V1 ≥ 60 µV

2.17 ST elevation

Say: "inferior ST elevation"
if: positive J amplitude in aVF ≥ 100 µV
and positive J amplitude ≥ 100 µV in II or III

Say: "high-lateral ST elevation"
if: positive J amplitude ≥ 100 µV in I and aVL

Say: "right-precordial ST elevation"
if: positive J amplitude ≥ 200 µV in V2 and V3

Say: "mid-precordial ST elevation"
if: positive J amplitude in V3 ≥ 200 µV
and positive J amplitude ≥ 100 µV in V4 and V5

Say: "left-precordial ST elevation"
if: positive J amplitude ≥ 100 µV in V5 and V6

2.18 ST and T abnormalities

Skip tests
if: test LBBB passed

Say: “consider pericarditis”
if: positive J amplitude > 120 μV in at least 3 of the extremity leads
and positive J amplitude > 120 μV in at least 6 of all leads
and heart rate ≥ 70 BPM
or positive J amplitude > 120 μV and positive T amplitude ≥ 50 μV in all leads

Say: “high T voltage, consider hyperkalemia”
if: 330 ≤ corrected QT interval < 470 ms
and positive T amplitude > 1000 μV in V3, V4, V5
or positive T amplitude > 1000 μV in V4, V5, V6

2.19 Repolarization

The negativity of the T wave in all leads except aVR and V1 is classified in one of the following categories:

“flat or low negative”:	positive T amplitude ≤ 50 µV and negative T amplitude ≤ 30 µV
“small negative”:	30 < negative T amplitude ≤ 100 µV
“negative”:	100 < negative T amplitude ≤ 250 µV
“large negative”:	250 < negative T amplitude ≤ 500 µV
“very large negative”:	negative T amplitude > 500 µV

Using this negative T wave classification, repolarization statements can be made for five different localizations: “inferior” (II, III, aVF), “high-lateral” (I, aVL), “right precordial” (V2, V3), “mid precordial” (V3, V4, V5), and “left precordial” (V5, V6). The severity of a repolarization disturbance is indicated by one of six possible grades: “minimal”, “minor”, “slight”, “moderate”, “marked”, “very marked”. The grades of severity are determined by considering the negativity of the T wave in the leads that are pertinent to a particular localization.

In general, the statement “very marked <loc> repolarization abnormality”, where <loc> denotes one of the five localizations mentioned above, requires a large negative T wave in at least one of the leads pertaining to that localization with additional less severe constraints on the remaining leads. In a similar way, the statement “marked <loc> repolarization disturbance” requires a large negative T wave in at least one of the relevant leads. Statements for “moderate“, “slight”, and “minimal” repolarization abnormality require negative, small negative, and flat or low negative T waves, respectively. Grade “minor” requires both small negative and flat or low negative T waves to be present.

After each repolarization statement, a statement as to the cause of the repolarization disturbance is appended. Depending on the T abnormalities found and possible other abnormalities, such as LVH or infarction, the program may append one of the following statements:

“, consider ischemia”
“, consider ischemia or LV overload”
“, consider ischemia and/or digitalis”
“, consider ischemia, LV overload and/or digitalis”
“ secondary to infarct”
“, consider infarct of recent occurrence”
“ secondary to LVH”
“ secondary to LVH, consider also infarct”
“ secondary to LVH, consider also ischemia”
“ secondary to infarct, consider also LV overload”
“ secondary to RVH”
“ secondary to RBBB”
“ secondary to LBBB”
“, consider juvenile pattern”
“, consider feminine pattern”
“, compatible with early repolarization”
“, consider acute infarct occurrence”
“, consider acute ischemia”
“, probably reciprocal”
“, consider ischemia, or non-specific change”
“, secondary to RVH and/or juvenile pattern”
“, secondary to RBBB and/or juvenile pattern”
“, consider juvenile and/or feminine pattern”
“, consider feminine pattern and/or ischemia”
“, consider ischemia, LV overload or –non-specific change”
“, probably non-specific change”

2.20 Miscellaneous

Skip tests
if: test RBBB passed
or test IRBBB passed
or test RVH passed

Say: “RSR′ in V1 and V2”
if: Q amplitude < 70 μV in V1 and V2
and R amplitude ≥ 60 μV in V1 and V2
and R′ amplitude ≥ 60 μV in V1 and V2
and S′ amplitude < 100 μV in V1 and V2

Say: “RSR′ in V1”
if: the above criteria apply to V1 only

Say: “RSR′ in V2”
if: the above criteria apply to V2 only

2.21 Interaction of statements

When the classification process leads to coexisting diagnostic statements, a weighing procedure may come into play to change the certainty qualifier of one or more of the statements. These changes are described below. The following hierarchy is adopted: “consider”, “possible”, “probable”, “definite” (the default value). The terms “pronounced” and “very pronounced” imply “definite” certainty but add a measure of severity.

LBBB and LVH:

When LBBB is at least “probable”, any concomitant LVH statement is suppressed if QRS duration is ≥ 140 ms. For QRS durations between 130 and 140 ms, the certainty of LBBB is lowered to “possible” and LVH is not suppressed.

If LBBB is “possible” and LVH is at least “probable”, the LBBB qualifier is lowered to “consider”.

LBBB and IVCD:

If QRS duration ≥ 180 ms, the LBBB qualifier is increased by one point, e.g., “possible” becomes “probable”. Any IVCD statement is suppressed in the presence of LBBB.

(I)RBBB and infarct:

In the presence of a septal or anterior infarct that is at least “probable”, the statement “consider also periinfarct block” is added to the RBBB statement.

The qualifier of an inferior infarct is lowered one point in the presence of RBBB.

Incomplete RBBB is suppressed if RVH or infarct is at least “probable”.

Any IVCD statement is suppressed in the presence of (I)RBBB.

LVH and infarct:

If the LVH qualifier is higher than the highest infarct qualifier, all infarct qualifiers are lowered one point. If the reverse is true, the LVH qualifier is lowered one point.

Lateral infarct and high-lateral infarct:

The infarct with lowest qualifier is suppressed, provided that no inferior infarct has been found.

ST elevation and LBBB, LVH, or ST depression:

An ST elevation statement is suppressed if the presence of LBBB is at least “probable” or if an LVH statement is made, unless an infarct statement is present with a stronger qualifier than LVH.

In the presence of ST elevation, repolarization disturbance statements at corresponding locations are suppressed. ST depression and ST elevation are considered to be mirror images, taking the inferior location to be mirrored in the other localizations and vice versa. For instance, if an inferior ST elevation is present as well as an high-lateral repolarization disturbance without high-lateral infarct, the statement “high-lateral ST depression” is generated, further high-lateral repolarization statements being suppressed. Similarly, the statements “right-precordial ST depression”, “mid-precordial ST depression”, “left-precordial ST depression”, and “inferior ST depression” can be generated.

2.22 Combination of statements

The program distinguishes six basic infarct locations: septal, anterior, lateral, high lateral, inferior, and posterior. If infarction is present at different locations, the program attempts to generate combined infarction statements. For instance, the statements “inferior infarct” and “posterior infarct” will be combined in the statement “inferoposterior infarct.” The degree of probability of the combined infarct is equal to the highest degree of the separate infarcts. Thus, “probable” infarct and “possible” infarct will combine to “probable.” The following combinations can be made:

“inferior”+“posterior”	→ “inferoposterior”
“posterior”+“lateral”	→ “posterolateral”
“inferior”+“lateral”	→ “inferolateral”
“inferior”+“posterior”+“lateral”	→ “inferoposterolateral”
“high lateral”+“lateral”	→ “high-lateral and lateral”
“anterior”+“lateral”	→ “anterolateral”
“anterior”+“lateral”+“high lateral”	→ “anterolateral and high-lateral”
“anterior”+“septal”	→ “anteroseptal”
“anterior”+“septal”+“lateral”	→ “extensive anterior”
“anterior”+“septal”+“lateral”+“high lateral”	→ “extensive anterior and high-lateral”

A similar procedure is followed for combining repolarization disturbances or ST elevation at different locations. For these abnormalities, locations “septal”, “anterior”, and “lateral” are renamed “right precordial”, “mid precordial”, and “left precordial”, respectively. The locations in the combined statements are adjusted accordingly.

3 Rhythm analysis

3.1 Introduction

In this section of the algorithm a wide range of diagnoses is offered. There are six basic processing steps:

1 The first aim of the algorithm is to detect artificial pacemaker spikes. If these are found, the program will issue an appropriate statement and stop. Contour analysis is performed if there are enough unpaced complexes.

2 If no artificial pacemaker spikes are detected, the program will try to find QRS complexes which do not conform to the dominant complexes in the ECG. These non-dominant complexes are analyzed, classified and discarded so that further rhythm analysis can be performed on sequences of complexes of the dominant type.

3 After this procedure, with only one type of QRS complexes left to analyze, the program will look for flutter waves. Finding no flutter waves does not automatically mean that the diagnosis of atrial flutter cannot be made. This precaution has been built in because it is not always possible for the computer to detect flutter waves.

4 For the actual rhythm analysis, a division is made between regular and irregular rhythms. A rhythm is judged to be regular if the difference between the maximum and minimum RR interval is less than 20% of the average RR interval. If there are RR intervals falling outside this range, the rhythm is categorized as irregular.

5 Subsequently, the algorithm checks which relationship exists between the dominant QRS complexes and P waves. There are several possibilities:

- There are no P waves found. The analyzed ECG falls into this category if fewer than 15% of the QRS complexes are preceded by P waves. This criterion has been built in to make allowance for the program detecting P waves by mistake.
- Some QRS complexes are preceded by P waves, but others are not. This category will be chosen if 15-90% of the QRS complexes are preceded by P waves.
- Each QRS complex is preceded by one and only one P wave. This category will be chosen if 90-100% of the QRS complexes is preceded by a P wave. This criterion was so formulated because it is possible that the program will incidentally miss a P wave.
- Some or all QRS complexes are preceded by more than one P wave. This implies that the number of P waves is larger than that of the QRS complexes.

6 A final distinction between the diagnostic groups is the constancy of the PR intervals. With difference between the largest PR interval and the shortest PR interval of less than 30 ms the interval is said to be constant.

Basic parameters such as the consistency of the RR interval, the P/QRS ratio, and the consistency of the PR interval are not the only characteristics upon which a diagnosis is based. Other features are used to form a statement, such as heart rate, type of the non-dominant complexes, QRS duration, and PP interval. Through combinations, it is possible to form more than ISO statements concerning the type of rhythm that is present.

The subsequent paragraphs in this chapter will describe the parameters that are used in rhythm analysis, the general structure of the decision tree, the categories of rhythm statements that have been distinguished, and the diagnostic criteria for the rhythm statements grouped according to category. A cross-reference list is provided for ease of finding the criteria for a specific statement.

3.2 Rhythm parameters

The following parameters are used in the criteria for documenting rhythms

- P/QRS ratio: ratio of the number of P waves to the number of dominant QRS complexes. (If used as a measure for atrial activity).
- PR range: difference between the maximum and minimum PR interval (in ms). It is used as a measure for the constancy of the PR interval.
- Type of QRS complex: classification of QRS complexes according to their morphology. Complexes with the same morphology belong to one type. A basic distinction is between the dominant and non-dominant types of QRS complexes. The latter group may consist of one or more types of non-dominant QRS complexes.
- RR interval: interval between two consecutive QRS complexes (in ms).
- PP interval: interval between two consecutive P waves (in ms).
- PR interval: interval between a dominant QRS complex and a preceding P wave (in ms).
- atrial rate: number of atrial contractions (in beats per minute, BPM).
- Ventricular rate: number of ventricular contractions (in BPM).
- Rate variation: difference between the maximum and minimum RR interval, normalized to the average RR interval. (If used as a measure for regularity of the rhythm).
- QRS duration: difference between the global onset and end of the QRS complex (in ms).
- P axis: axis of the P wave in the frontal plane, using the areas under the P waves in lead I and II (in degrees).
- negative P amplitude (in µV): absolute value of the negative deflection of the P wave.

3.3 Decision tree

The decision tree for the rhythm analysis is shown in Figure 1 on page 36. The program starts at the top decision node and proceeds depending on the value of the test. If the condition in the decision node is met, the branch marked by “yes” is taken. If not, the “no”-branch is followed. First, the activity of an artificial pacemaker, the occurrence of more than one type of QRS complexes (non-dominant complexes), and the presence of atrial flutter waves is tested. In presence of pacemaker spikes or flutter waves, an appropriate statement is issued and the rhythm analysis stops. If non-dominant complexes are also present, the type of arrhythmia is described. The non-dominant complexes are then discarded from further consideration and the analysis proceeds. Thus, after this first phase, only one type of QRS complex (the dominant complexes) is analyzed.

Second, regular rhythms are distinguished from irregular ones based on the consistency of the RR intervals. Both types of rhythm are subdivided in to different groups depending on the number of P waves versus the number of QRS complexes (P/QRS ratio) and on the consistency of the PR interval (PR range). The irregularity of a rhythm may be brief local. The program then describes the abnormality and discards the relevant complexes, similar to the way non-dominant complexes are handled. If the resultant rhythm, after removal of the atypical complexes, is regular, the rhythm is analyzed in the regular rhythm part of the program.

In Table 3 the various groups are listed together with a characterization of the types of arrhythmia in each group.

Table 3. Grouping of arrhythmias as used in the rhythm analysis program.

Group	Description
1	Rhythms with artificial pacemaker spikes
2	Non-dominant QRS complexes
3	Rhythms with atrial flutter or tachycardia
4	Regular rhythms with P/QRS ≤ 0.15
5	Regular rhythms with 0.15 < P/QRS ≤ 1.0 and PR range > 60 ms
6	Regular rhythms with P/QRS > 1.0 and PR range ≤ 30 ms
7	Regular rhythms with P/QRS > 1.0 and PR range > 30 ms
8	Irregular rhythms with P/QRS ≤ 0.15
9	Rhythms with paroxysmal acceleration or deceleration of the ventricular rate
10	Irregular rhythms with 0.15 < P/QRS ≤ 0.9 and PR range ≤ 30 ms
11	Irregular rhythms with 0.15 < P/QRS ≤ 0.9 and PR range > 30 ms
12	Irregular rhythms with 0.9 < P/QRS ≤ 1.2 and PR range > 30 ms
13	Irregular rhythms with P/QRS > 1.2 and PR range > 30 ms
14	Irregular rhythms with P/QRS > 1.0 and PR range ≤ 30 ms
15	Rhythms with constant PR interval

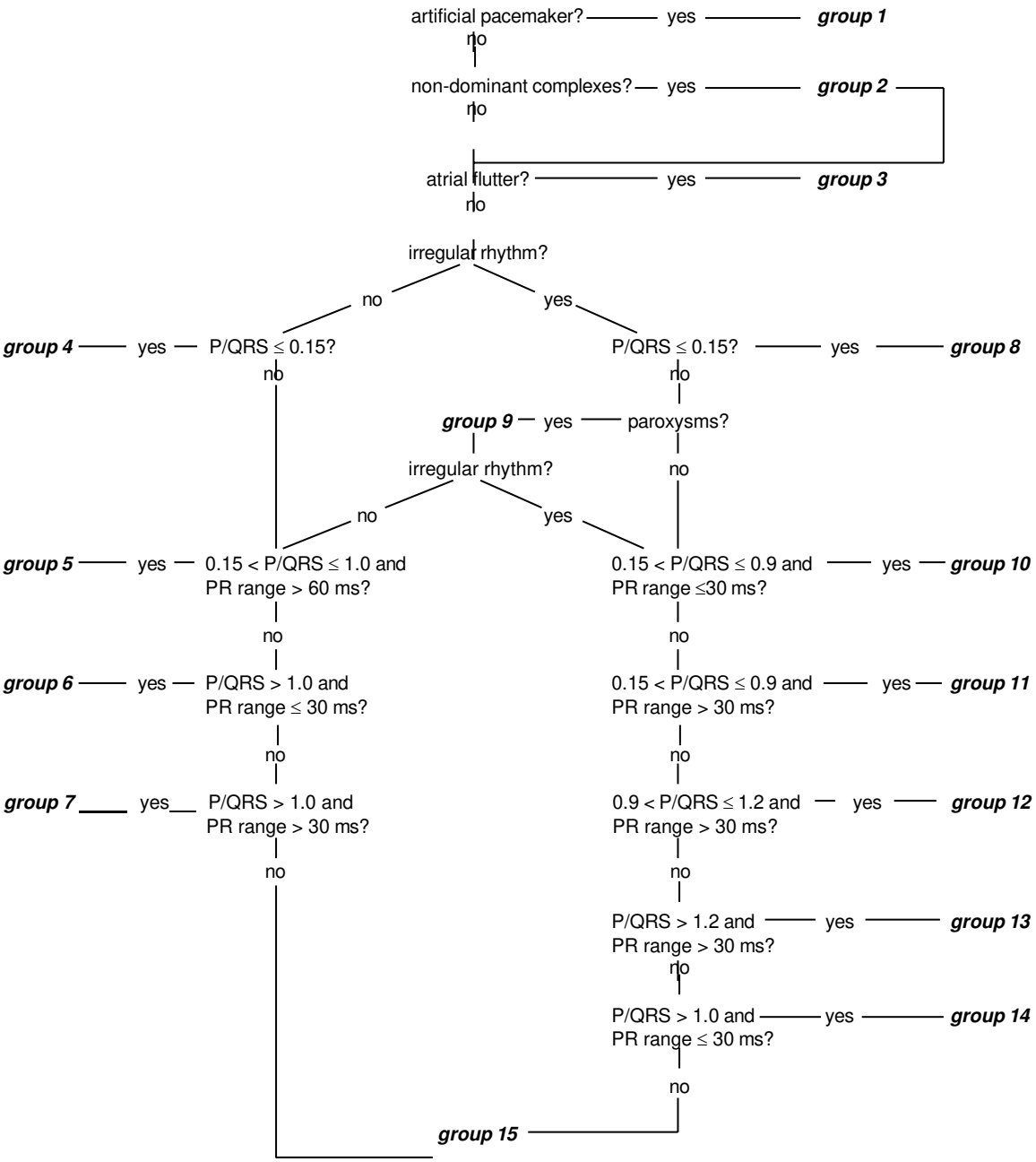

Figure 1 . Structure of the decision tree for rhythm classification.

3.4 Group 1: Rhythms with artificial pacemaker spikes

Artificial pacemaker spikes may have been detected by the measurement part of the program. If so, a general statement will be issued and the program halts. No attempt is made to specify the type of pacemaker, frequency, or functioning of the demand mechanism.

Say: "artificial pacemaker rhythm"
if: artificial pacemaker spikes have been found

3.5 Group 2: Non-dominant QRS complexes

Non-dominant QRS complexes can be classified in different categories. First, a test is performed on the occurrence of short paroxysms of at least three complexes ("runs"). To qualify as a run, its rate should exceed the inherent rate of the subsidiary pacemaker by 20% and the number of complexes belonging to the run should be less than 90% of the total number of QRS complexes. The identified non-dominant complexes are discarded and the program continues with the classification of the non-dominant complexes that are still present in the recording.

Second, consecutive non-dominant complexes without an acceleration of the QRS rate are searched for. Depending on the number of complexes found, the term "doublet" (two consecutive complexes) or "sequence" (three or more complexes) is used. One of the parameters considered here is the length of the RR interval preceding the first non-dominant complex of the doublet or sequence (the coupling interval) relative to the RR interval of the basic rhythm (RR ratio). This parameter is used to distinguish between premature beats and an escape rhythm. Again, complexes are discarded after their classification.

Following this, a test is performed for the presence of a bigeminy, i.e., for the alternation of the dominant QRS type with another (or others), whether continuously or only during part of the recording. If an alternation of QRS types is present during the entire recording, a special test is made for the presence of a ventricular escape-capture bigeminy.

Finally, the type of the remaining single non-dominant complexes is classified according to the QRS width and the duration of preceding RR interval. Coupling intervals (the interval between the ectopic complex and the preceding dominant QRS complex) are considered constant if the range of these intervals does not exceed 80 ms.

The classification of non-dominant complexes may need adjustment in the presence of some rhythms that are classified at a later stage of the rhythm analysis. The alterations are explained in the last paragraph of this section.

Run of non-dominant complexes

Say: “with run of multiform premature ventricular complexes”
if: more than one type of non-dominant complexes is in the run

Say: “with accelerated ectopic rhythm”
if: one type of non-dominant complexes is in the run
and the run rate is $\leq$ 100 BPM

Say: “with supraventricular tachycardia with aberrant ventricular conduction,”
“ consider ventricular tachycardia”
if: one type of non-dominant complexes is in the run
and the run rate is > 100 BPM
and QRS duration in the run is $\leq$ 120 ms

Say: “with (probably) ventricular tachycardia,”
“consider supraventricular tachycardia with aberrant ventricular conduction”
if: one type of non-dominant complexes is in the run
and the run rate is > 100 BPM
and the QRS duration in the run is > 120 ms

Doublet or sequence of non-dominant complexes

Say: “doublets of multiform premature ventricular complexes”
or
“sequence of multiform premature ventricular complexes”
if: more than one type of non-dominant consecutive complexes is present

Say: “doublets of supraventricular escapes with aberrant ventricular conduction, cause?”
or
“sequence of supraventricular escapes with aberrant ventricular conduction, cause?
eg SA block?”
if: one type of non-dominant consecutive complexes is present
and the QRS duration of the non-dominant complexes is ≤ 120 ms
and the RR ratio is> 1.2

Say: “doublets of ventricular escapes, cause?”
or
“sequence of ventricular escapes, cause? eg AV block?”
if: one type of non-dominant consecutive complexes is present
and the QRS duration of the non-dominant complexes is > 120 ms
and the RR ratio > 1.2

Say: “doublets of aberrantly conducted complexes”
or
“sequence of aberrantly conducted complexes”
if: one type of non-dominant consecutive complexes is present
and the 0.9 < RR ratio is ≤ 1.2

Say: “doublets of premature supraventricular complexes with aberrant ventricular conduction”
or
“sequence of supraventricular complexes with aberrant ventricular conduction”
if: one type of non-dominant consecutive complexes is present
and QRS duration non-dominant complexes ≤ 120 ms
and the RR ratio is ≤ 0.9

Say: “doublets of premature ventricular complexes”
or
“sequence of ventricular complexes”
if: one type of non-dominant consecutive complexes is present
and the QRS duration non-dominant complexes is > 120 ms
and RR ratio ≤ 0.9

Alternating dominant and non-dominant complexes

Say: “bigeminal rhythm, consider escape-capture bigeminy”
if: alternating dominant/non-dominant complexes in the whole recording
and one type of non-dominant consecutive complexes
and QRS duration non-dominant complexes ≤ 120 ms
and RR preceding non-dominant < RR preceding dominant complexes
and no P preceding dominant QRS complexes

Say: “as a bigeminal rhythm”
if: alternating dominant/non-dominant complexes in the whole recording
and failure to meet one or more of the other criteria above

Say: “episode of bigeminal rhythm”
if: alternating dominant/non-dominant complexes for at least three consecutive times but not in the whole recording

Isolated non-dominant complexes

Say: "premature ventricular complexes with variable coupling intervals,"
"consider ventricular parasystole"
if: QRS duration non-dominant complexes > 120 ms
and coupling interval range > 80 ms

Say: "multiform premature ventricular complexes"
or
"premature ventricular complexes"
if: QRS duration non-dominant complexes > 120 ms
and coupling interval range ≤ 80 ms
and RR ratio < 0.9

Say: "ventricular escapes, cause? eg AV block?"
if: QRS duration non-dominant complexes > ULN + 20 ms
and coupling interval range ≤ 80 ms
and RR ratio > 1.2

Say: "aberrantly conducted complexes"
if: 0.9 < RR ratio ≤ 1.2

Say: "premature supraventricular complexes with aberrant ventricular conduction and variable coupling intervals," "consider supraventricular parasystole"
if: QRS duration non-dominant complexes ≤ 100 ms
and coupling interval range > 80 ms

Say: "supraventricular escapes with aberrant ventricular conduction, cause? eg SA block?"
if: QRS duration non-dominant complexes ≤ 100 ms
and coupling interval range ≤ 80 ms
and RR ratio > 1.2

Say: "premature supraventricular complexes with aberrant ventricular conduction"
or
"premature supraventricular complexes with variable aberrant ventricular conduction"
if: QRS duration non-dominant complexes ≤ 100 ms
and coupling interval range ≤ 80 ms
and RR ratio ≤ 0.9

Say: "premature ventricular complexes or premature supraventricular complexes with aberrant ventricular conduction, with variable coupling intervals," "consider parasystole"
if: 100 < QRS duration non-dominant complexes ≤ 120 ms
and coupling interval range > 80 ms

Say: "premature ventricular complexes or premature supraventricular complexes with aberrant ventricular conduction"
or
"multiform premature ventricular complexes and/or premature supraventricular complexes with (variable) aberrant ventricular conduction"
if: 100 < QRS duration non-dominant complexes ≤ 120 ms
and coupling interval range ≤ 80 ms
and RR ratio ≤ 0.9

Say: "ventricular escapes or supraventricular escapes with aberrant ventricular conduction, cause?"
if: 100 < QRS duration non-dominant complexes ≤ 120 ms
and coupling interval range ≤ 80 ms
and RR ratio > 1.2

Modification of statements

The program classifies the non-dominant complexes before it classifies the rhythm, assuming that both classifications are not contradictory. However, in the presence of atrial fibrillation, atrial flutter, atrial tachycardia, second degree AV block, or advanced AV block, a detailed classification of the non-dominant complexes is considered too difficult. Any statement on sequences, doublets or isolated non-dominant complexes will then be replaced with the general statement:

> “premature ventricular complexes or aberrantly conducted complexes”

3.6 Group 3: Rhythms with atrial flutter or tachycardia

In atrial flutter, the atrial activity is represented in the ECG by regular, saw-tooth like oscillations (F waves) which occur at rates between 220 and 400 beats per minute (BPM). The measurement part of the program contains a routine for the detection of F waves. If F waves are detected, but the rate of the atrial activity is less than 220 BPM, a classification of atrial tachycardia is made.

Say: “atrial tachycardia”
if: atrial rate ≤ 220 BPM

Say: “atrial flutter”
if: atrial rate > 220 BPM

Say: “with second degree AV block at variable conduction ratio”
if: rate variation > 20%

Say: “with second degree AV block at N:1 conduction ratio”
if: rate variation ≤ 20%
and atrial rate is an integer multiple N of ventricular rate

Say: “with complete AV block”
if: rate variation ≤ 20%
and atrial rate is not an integer multiple of ventricular rate
and heart rate < LLN

Say: “with block or interference in the AV junction”
if: rate variation ≤ 20%
and atrial rate is not an integer multiple of ventricular rate
and heart rate ≥ LLN

In the presence of atrial flutter without the characteristic saw-tooth appearance, F waves may be mistaken for P waves by the program. If the shortest PP interval found is shorter than 300 ms, corresponding with an atrial rate exceeding 220 BPM, atrial flutter may still correctly be classified.

Say: “atrial flutter with advanced AV block”
if: shortest PP interval < 300 ms
and rate variation ≤ 20%

Say: “atrial flutter with second degree AV block at variable conduction ratio”
if: shortest PP interval < 300 ms
and rate variation > 20%

3.7 Group 4: Regular rhythms with P/QRS ≤ 0.15

Say: “idioventricular rhythm (no atrial activity detected”
if: QRS duration ≥ 120 ms
and heart rate < 40 BPM

Say: “AV junctional rhythm with aberrant ventricular conduction or”
“ accelerated idioventricular rhythm (no atrial activity detected)”
if: QRS duration ≥ 120 ms
and 40 ≤ heart rate < 60 BPM

Say: “accelerated AV junctional rhythm with aberrant ventricular conduction or”
“ accelerated idioventricular rhythm (no atrial activity detected)”
if: QRS duration ≥ 120 ms
and 60 ≤ heart rate < 100 BPM

Say: “AV junctional tachycardia with aberrant ventricular conduction,”
“ consider ventricular tachycardia (no atrial activity detected)”
if: QRS duration ≥ 120 ms
and 100 ≤ heart rate < 120 BPM

Say: “supraventricular tachycardia with aberrant ventricular conduction,” “consider ventricular tachycardia”
if: QRS duration ≥ 120 ms
and 120 ≤ heart rate < 140 BPM

Say: “supraventricular tachycardia with aberrant ventricular conduction,” “consider ventricular tachycardia”
if: QRS duration ≥ 120 ms
and 140 ≤ heart rate < 200 BPM

Say: “supraventricular tachycardia with aberrant ventricular conduction and very high ventricular rate,”
“ or ventricular tachycardia”
if: QRS duration ≥ 120 ms
and heart rate ≥ 200 BPM

Say: “AV junctional rhythm (no atrial activity detected)”
if: QRS duration < 120 ms
and heart rate < 60 BPM

Say: “accelerated AV junctional rhythm (no atrial activity detected”
if: QRS duration < 120 ms
and 60 ≤ heart rate < 100 BPM

Say: “AV junctional tachycardia (no atrial activity detected)”
if: QRS duration < 120 ms
and 100 ≤ heart rate < 120 BPM

Say: “supraventricular tachycardia, consider atrial flutter with 2:1 A-V conduction”
if: QRS duration < 120 ms
and 120 ≤ heart rate < 140 BPM

Say: “supraventricular tachycardia (atrial flutter or atrial tachycardia)”
if: QRS duration < 120 ms
and 140 ≤ heart rate < 200 BPM

Say: “supraventricular tachycardia with very high ventricular rate”
if: QRS duration < 120 ms
and heart rate ≥ 200 BPM

3.8 Group 5: Regular rhythms with 0.15<P/QRS≤1.0 and PR range > 60 ms

Say: “sinus rhythm with complete AV block; idioventricular escape rhythm”
if: heart rate < 40 BPM
and QRS duration ≥ 120 ms

Say: “sinus rhythm with complete AV block; accelerated idioventricular escape rhythm,”
“ consider AV junctional rhythm with aberrant ventricular conduction”
if: 40 ≤ heart rate < 60 BPM
and QRS duration ≥ 120 ms

Say: “sinus rhythm with block and/or interference in the AV junction;”
“ accelerated AV junctional rhythm with aberrant ventricular conduction,”
“ consider ventricular tachycardia”
if: 60 ≤ heart rate < 100 BPM
and QRS duration ≥ 120 ms

Say: “sinus rhythm with block and/or interference in the AV junction;”
“ AV junctional tachycardia with aberrant ventricular conduction,”
“ consider ventricular tachycardia”
if: heart rate ≥ 100 BPM
and QRS duration ≥ 120 ms

Say: “sinus rhythm with complete AV block; AV junctional escape rhythm”
if: heart rate < 60 BPM
and QRS duration < 120 ms

Say: “sinus rhythm with block and/or interference in the AV junction;”
“ accelerated AV junctional rhythm”
if: 60 ≤ heart rate < 100 BPM
and QRS duration < 120 ms

Say: “supraventricular tachycardia with block and/or interference in the AV junction”
if: 100 ≤ heart rate < 140 BPM
and QRS duration < 120 ms

Say: “supraventricular tachycardia,”
“ consider atrial flutter with second degree AV block at 2:1 conduction ratio”
if: heart rate ≥ 140 BPM
and QRS duration < 120 ms

3.9 Group 6: Regular rhythms with P/QRS > 1.0 and PR range ≤ 30 ms

Say: “atrial flutter”
if: shortest PP interval < 300 ms

Say: “atrial tachycardia”
if: 300 ≤ shortest PP interval < 370 ms

Say: “sinus tachycardia”
if: 370 ≤ shortest PP interval < 600 ms

Say: “sinus rhythm”
if: shortest PP interval > 600 ms

Say: “with second degree AV block at N:1 conduction ratio”
if: atrial rate is an integer multiple N of ventricular rate

Say: “with advanced AV block at variable conduction ratio”
if: atrial rate is not an integer multiple of ventricular rate

3.10 Group 7: Regular rhythms with P/QRS > 1.0 and PR range > 30 ms

Say: “atrial tachycardia”
if: 300 ≤ shortest PP interval < 370 ms

Say: “sinus tachycardia”
if: 370 ≤ shortest PP interval < 600 ms

Say: “sinus rhythm”
if: shortest PP interval ≥ 600 ms

Say: “with second degree AV block at 2:1 conduction ratio”
if: shortest PR interval > 120 ms
and 1.75 < P/QRS ratio ≤ 2.0

If the criteria for a 2:1 AV block are not fulfilled, an AV dissociation due to block or interference is assumed.

Say: “with complete AV block”
“idioventricular escape rhythm”
if: QRS duration ≥ 120 ms
and heart rate < 40 BPM

Say: “with complete AV block”
“ accelerated idioventricular escape rhythm,”
“ consider AV junctional rhythm with aberrant ventricular conduction”
if: QRS duration ≥ 120 ms
and 40 BPM ≤ heart rate < 60 BPM

Say: “with block and/or interference in the AV junction”
“accelerated AV junctional rhythm with aberrant ventricular conduction,”
“ consider ventricular tachycardia”
if: QRS duration ≥ 120 ms
and 60 ≤ heart rate < 100 BPM

Say: “with block and/or interference in the AV junction”
“AV junctional tachycardia with aberrant ventricular conduction,”
“ consider ventricular tachycardia”
if: QRS duration ≥ 120 ms
and heart rate ≥ 100 BPM

Say: “with complete AV block”
“AV junctional escape rhythm”
if: QRS duration < 120 ms
and heart rate < 60 BPM

Say: “with block and/or interference in the AV junction”
“accelerated AV junctional rhythm”
if: QRS duration < 120 ms
and 60 ≤ heart rate < 100 BPM

Say: “with block and/or interference in the AV junction”
“AV junctional tachycardia”
if: QRS duration < 120 ms
and heart rate ≥ 100 BPM

3.11 Group 8: Irregular rhythms with P/QRS ≤ 0.15

Say: "atrial fibrillation with slow mean ventricular response"
if: heart rate < 50 BPM

Say: "atrial fibrillation with normal mean ventricular response"
if: 50 ≤ heart rate < 100 BPM

Say: "atrial fibrillation with rapid mean ventricular response"
if: 100 ≤ heart rate < 180 BPM

Say: "atrial fibrillation with very rapid mean ventricular response"
if: heart rate ≥ 180 BPM

Say: " with long RR intervals"
if: there is an RR interval > 1.6 s

3.12 Group 9: Rhythms with paroxysmal acceleration or deceleration of ventricular rate

The program defines a paroxysmal acceleration ("run") as a sequence of three or more dominant complexes with a rate that exceeds the inherent rate of the subsidiary pacemaker by 40%. Once a run has been detected and classified, the complexes are discarded. The remaining rhythm, which may be perfectly regular, is classified separately.

Say: " with run of dominant complexes"
if: there is a run
and run rate < 140 BPM

Say: " with episode of paroxysmal junctional tachycardia"
if: there is a run
and 140 < run rate ≤ 160 BPM

Say: " with episode of paroxysmal atrial tachycardia"
if: there is a run
and run rate > 160 BPM

An arrest is defined as a transient disturbance in impulse formation giving rise to an RR interval which is at least 50% longer than the average RR interval and has a duration of at least 2 s.

Say: " with ventricular arrest"
if: there is an arrest

3.13 Group 10: Irregular rhythms with 0.15 < P/QRS ≤ 0.9 and PR range ≤ 30 ms

First, a test is made on the alternation of RR intervals with and without a P wave to rule out a bigeminal rhythm due to sinus rhythm with atrial or AV junctional premature complexes. If a bigeminal rhythm is found the program halts. If not, tests are performed on each RR interval in which no P wave has been detected. If the interval is shortened, a premature supraventricular complex is assumed; if it is prolonged, an AV junctional escape is assumed. The shortened or prolonged RR intervals are deleted after they have been analyzed and the program continues with the logic for rhythms with constant PR intervals.

Say: "bigeminy: sinus rhythm with alternate premature supraventricular complexes"
if: P/QRS ratio ≥ 0.4
and test bigeminy passed

Say: "premature supraventricular complexes"
if: test PSVC passed
and test bigeminy failed

Say: "AV junctional escapes, cause? eg SA block or AV block?"
if: test escape passed
and test bigeminy failed

Say: "consider premature supraventricular complexes"
if: test bigeminy failed
and test PSVC failed
and test escape failed

3.14 Group 11: Irregular rhythms with 0.15 < P/QRS ≤ 0.9 and PR range > 30 ms

If the number of P waves is small, no further specification of the atrial rhythm is given. Otherwise, it is tested whether there exists a second degree AV block of the Wenckebach type. Three conditions should be met for this test to pass: (1) the maximal RR interval should exceed the minimal RR interval by at least 40%, (2) the RR interval preceding the longest RR interval should be shorter than the one following the longest RR interval, and (3) the shortest PR interval should be found in the longest RR interval. If this test fails, a distinction is to be made between AV dissociation and sinus rhythm with ectopic complexes of supraventricular origin.

Say: "undetermined atrial rhythm with block and/or interference in the AV junction"
"consider atrial fibrillation"
if: P/QRS ratio < 0.3

Say: "sinus rhythm with second degree AV block, type I (Wenckebach)"
if: P/QRS ratio ≥ 0.3
and test Wenckebach passed

Say: "undetermined atrial rhythm with block and/or interference in the AV junction"
if: PR range > 120 ms

Say: "supraventricular escapes, cause? eg AV block, SA block?"
if: 60 < PR range ≤ 120 ms
and heart rate < 50 BPM

Say: "consider supraventricular escapes, cause? eg AV block, SA block?"
if: 30 < PR range ≤ 60 ms
and heart rate < 50 BPM

Say: "premature atrial complexes"
if: 60 < PR range ≤ 120 ms
and heart rate ≥ 50 BPM

Say: "consider premature atrial complexes"
if: 30 < PR range ≤ 60 ms
and heart rate ≥ 50 BPM

Say: "sinus bradycardia"
if: heart rate < 50 BPM

Say: "sinus rhythm"
if: 50 ≤ heart rate < 100 BPM

Say: "sinus tachycardia"
if: heart rate ≥ 100 BPM

3.15 Group 12: Irregular rhythms with 0.9 < P/QRS ≤ 1.2 and PR range > 30 ms

The presence of a second degree AV block of the Wenckebach type is considered by performing the Wenckebach test as described in the previous paragraph. If it fails, a test is performed on the PR range in the RR intervals of about equal length. If this range is large, sinus rhythm with block or interference in the AV junction is considered. If not, the rhythm is considered to consist of sinus rhythm complicated by ectopic supraventricular impulses. To distinguish between escapes and premature supraventricular complexes, a test is performed on the sequence of short and long RR intervals.

Say: "sinus rhythm with second degree AV block, type I (Wenckebach)"
if: test Wenckebach passed

Say: "sinus rhythm with block and/or interference in the AV junction"
if: PR range ≥ 120 ms

Say: "sinus bradycardia"
if: heart rate < 50 BPM

Say: "sinus rhythm"
if: 50 ≤ heart rate < 100 BPM

Say: "sinus tachycardia"
if: heart rate ≥ 100 BPM

Say: "supraventricular escapes, cause? eg SA block or AV block?"
if: test escape passed

Say: "premature supraventricular complexes"
if: test escape failed

3.16 Group 13: Irregular rhythms with P/QRS > 1.2 and PR range > 30 ms

Say: "supraventricular (sinus?) tachycardia with second degree AV block at variable conduction ratio"
if: 300 ≤ shortest PP interval < 600 ms

Say: "sinus rhythm with second degree AV block at variable conduction ratio"
if: shortest PP interval ≥ 600 ms

3.17 Group 14: Irregular rhythms with P/QRS > 1.0 and PR range ≤ 30 ms

The irregularity of the ventricular rhythm combined with the constancy of the PR interval and a higher number of P waves than QRS complexes implies that either a second degree AV block with constant preceding conduction times (Mobitz type II) or advanced AV block with varying conduction ratios is present. In case of Mobitz type II AV block, the longer RR intervals will most likely be sandwiched between shorter RR intervals. This is unlikely to occur in cases with advanced AV block with varying conduction ratios.

Say: "atrial flutter"
if: shortest PP interval < 300 ms

Say: "atrial tachycardia"
if: 300 ≤ shortest PP interval < 370 ms

Say: "sinus tachycardia"
if: 370 ≤ shortest PP interval < 600 ms

Say: "sinus rhythm"
if: shortest PP interval ≥ 600 ms

Say: "with second degree AV block, type II (Mobitz II)"
if: varying RR intervals fulfilling Mobitz II criteria

Say: "with second degree AV block at variable conduction ratio"
if: RR intervals not fulfilling Mobitz II criteria

3.18 Group 15: Rhythms with constant PR interval

In this group rhythms with constant PR interval are classified that either did not qualify for analysis in one of the previous groups or have only partly been analyzed there (see Figure 1). Rhythms that were not yet analyzed comprise regular and irregular rhythms with 0.9 < P/QRS ratio ≤ 1.0 and PR range ≤ 30 ms. The rhythms of this group may be classified as uncomplicated sinus rhythm as far as SA and AV conduction are concerned, provided they have a normal P wave axis and PR interval.

First, a test for premature supraventricular complexes is performed as these complexes may still be present if the rate variation is large. Second, if the rhythm is regular with a PR interval variation between 30 and 60 ms while the number of P waves found is less than the number of QRS complexes, a pacemaker shift should be considered. (If the PR range exceeds 60 ms, the rhythm has been taken care of in group 5.) Third, if the program detects a negative P axis with a sufficiently negative P-wave amplitude in aVF, an ectopic atrial rhythm or an AV junctional rhythm is considered present, depending on the length of the PR interval and the program halts. If not, various types of sinus rhythm can be classified, with or without arrhythmia dependent on the rate variation. Finally, the presence of first degree AV block, corrected for heart rate, is tested at different levels of severity. The PR interval limits used by the program are shown in Table 4.

Say: “premature supraventricular complexes”
if: test PSVC passed

Say: “PR interval variation: pacemaker shift?”
if: 30 < PR range ≤ 60 ms
and P/QRS < 1.0

Say: “AV junctional rhythm”
if: P axis ≤ −30°
and negative P amplitude in aVF > 70 µV
and PR interval ≤ 80 ms

Say: “ectopic atrial rhythm”
if: P axis ≤ −30°
and negative P amplitude in aVF > 70 µV
and PR interval > 80 ms

Say: “sinus bradycardia with sinus arrhythmia”
if: heart rate < 50 BPM
and rate variation > 20%

Say: “sinus arrhythmia”
if: 50 ≤ heart rate < 100 BPM
and rate variation > 20%

Say: “sinus tachycardia with sinus arrhythmia”
if: heart rate ≥ 100 BPM
and rate variation > 20%

Say: “extreme bradycardia, consider sinus rhythm with 2:1 AV conduction”
if: heart rate < 40 BPM
and rate variation ≤ 20%

Say: “sinus bradycardia”
if: 40 ≤ heart rate < 50 BPM
and rate variation ≤ 20%

Say: “sinus rhythm (slow)”
if: 50 ≤ heart rate < 60 BPM
and rate variation ≤ 20%

Say: “sinus rhythm”
if: 60 ≤ heart rate < 90 BPM
and rate variation ≤ 20%

Say: “sinus rhythm (rapid)”
if: 90 ≤ heart rate < 100 BPM
and rate variation ≤ 20%

Say: “sinus tachycardia”
if: heart rate ≥ 100 BPM
and rate variation ≤ 20%

Say: “short PR interval”
if: PR interval < 120 ms
and heart rate < 140 BPM

Say: “first degree AV block (limited)”
or
“first degree AV block”
or
“first degree AV block (extensive) ”
if: the appropriate limit from Table 4 is met

Table 4. PR intervals limits (in ms) for first degree AV block at different levels of severity. Limits are heart-rate dependent.

severity	heart rate				
	≤ 70	71-90	91-110	111-130	> 130
limited	220	210	200	190	180
typical	260	248	235	222	210
extensive	300	285	270	255	240

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5 The Performance of MEANS

Development of the Modular ECG Analysis System (MEANS) is an ongoing process. While the basic structure of the program has remained the same over the years, most program modules have undergone important changes. In the past, the performance of the different modules of MEANS has been assessed both by the program developers themselves and by independent observers. An independent assessment has been carried out during the project Common Standards for Quantitative Electrocardiography (CSE), an international study in which all major ECG computer programs were evaluated with respect to signal-analysis and diagnostic interpretation [1]. The final CSE results on waveform recognition were obtained in 1987 [2], those on diagnostic interpretation in 1990 [3]. Since then, many modifications have been made in the MEANS package. This report describes the performance of MEANS (version DB.AI) on the CSE waveform-recognition measurement and contour databases.

Methods

CSE waveform-recognition measurement database

The CSE database on waveform recognition contains 250 ECGs, but reference locations (onset and offset of the P wave and the QRS complex and end of the T wave) have been made public for only half of the ECGs. The 125 waveforms from the M01 data set have been evaluated. Tests have been removed from the evaluation of the M01 data set per 60601-2-51 clauses 50.101.1.3 and 50.101.3.2. The removed tests include test numbers: 006, 010, 018, 020, 023, 045, 050, 052, 054, 056, 057, 067, 070, 092, 093, 094, 100, 109, 111, 117, 119, 120, 121, and 122.

CSE contour diagnostic database

The CSE contour diagnostic database consists of 1,220 ECGs, divided over eight categories: normal (NOR), left ventricular hypertrophy (LVH), right ventricular hypertrophy (RVH), biventricular hypertrophy (BVH), anterior myocardial infarction (AMI), inferior myocardial infarction (IMI), combined infarction (MIX), and combined ventricular hypertrophy and myocardial infarction (VH+MI). Two reference standards are available per ECG: one is based on ECG-independent clinical information (“clinical truth”), the other is the combination of interpretations from a group of cardiologists (“combined referee”). These reference standards remain under lock and key at the present CSE processing center in Lyon (head: Dr. P. Rubel). Collection and composition of the database have been described in detail before [4, p 49-82].

All 1,220 ECGs were processed by MEANS using MEANS (version DB.AI). Diagnostic statements produced by MEANS were mapped onto a set of diagnostic codes as prescribed by the CSE protocol [4, p 83-104]. These codes were submitted to the CSE processing center in Lyon where the program results were compared with the reference standards. Classification matrices and summary statistics are documented below.

Results

Waveform recognition

Table 1. Interval measurements on biological ECGs - mean differences and standard deviations for global durations and intervals. Collected in conformity with the procedure used in the CSE study [2].

Global measurement	Calculated mean difference (ms)	Calculated standard deviation (ms)	Comments
P-duration	3.2	9.9	
PQ-interval	1.0	8.2	
QRS-duration	3.1	9.4	
QT-interval	3.2	12.0	

Table 2. Accuracy of diagnostic interpretative statements on the CSE contour diagnostic database vs. clinical truth

Diagnostic Category	No. of ECGs tested	Sensitivity; %	Specificity: %	Positive predictive value %	Comments
Normal	381	96.6	72.7	61.9	
LVH	181	59.7	97.8	82.9	
RVH	52	20.2	100.0	100.0	
BVH	51	32.4	100.0	100.0	
AMI	170	77.9	97.3	82.3	
IMI	273	63.9	98.5	92.3	
MIX	73	62.0	99.7	93.8	
VH+MI	31	50.0	100.0	100.0	
HYPER	N/A	49.3	98.3	89.0	
MI	N/A	68.7	94.3	90.8	

Table 3. Accuracy of diagnostic interpretative statements on the CSE contour diagnostic database vs. combined referee.

Diagnostic Category	No. of ECGs tested	Sensitivity; %	Specificity: %	Positive predictive value %	Comments
Normal	381	98.4	51.9	98.2	
LVH	181	82.0	89.9	94.8	
RVH	52	40.1	100.0	100.0	
BVH	51	69.6	98.2	97.0	
AMI	170	89.1	89.0	98.0	
IMI	273	78.7	89.6	96.5	
MIX	73	79.6	87.9	95.7	
VH+MI	31	81.1	96.0	96.8	
HYPER	N/A	N/A	N/A	N/A	
MI	N/A	82.9	91.5	97.9	

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