Pediatric MEANS (PEDMEANS) ECG Physicians' Manual for Norav Medical PC-ECG 1200 Electrocardiographs

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Caution

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 Pediatric Modular ECG Analysis System, PEDMEANS. PEDMEANS 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.

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1 Introduction

The PEDMEANS algorithm covers ages from 1 day through 17 years.

The way that a computer follows in the interpretation of a signal such as the electrocardiogram (ECG) differs fundamentally from those by which a human observer arrives at its understanding. 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 diagnostic criteria in this manual assume the pediatric ECGs to be recorded with lead V3R instead of V3 and lead V7 instead of V5, following common practice in The Netherlands. The Norav Medical PC-ECG 1200 electrocardiographs also allow for pediatric ECGs to be performed using the standard lead set. The PEDMEANS algorithm can analyze this data and provide both measurements and interpretive statements.

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 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. 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, 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 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.

Diagnostic interpretation of pediatric ECGs, much more than adult ECGs, relies on the use of age-dependent normal values in the classification rules. Normal limits of the pediatric ECG have been established in the past, but each of these studies has its deficiencies. Therefore, during the development of the interpretation program described in this manual a new set of normal limits was established using a data set of about 2,000 ECGs from normal children aged 0 to 16 years. Continuous age-dependent curves were calculated for the upper limit of normal (taken as the 98th percentile) and the lower limit of normal (2nd percentile), for all parameters used in the diagnostic interpretation. These curves avoid abrupt changes in diagnosis with small differences in age. In Appendix A (page 51) approximations of the continuous age-dependent normal limits are presented in tabular form.

1.5 Outline of the manual

This manual consists of two main parts. One part describes the diagnostic criteria that are employed in the contour classification of the Pediatric Modular ECG Analysis System (PEDMEANS), the other describes the criteria used in the rhythm classification of PEDMEANS. 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 47.

For each statement that can be issued, the criteria are specified in a general format. For example:

```
Say:    "WPW"
if:     delta wave in at least 2 leads
and             PR interval > ULN
        or      QRS duration > ULN
```

This means that the program will issue the statement "WPW" if delta waves are found in two or more leads and either the PR interval or the QRS duration is greater than the upper limit of normal for age. The upper limit of normal (ULN) and the lower limit of normal (LLN) denote the age-related 98th and 2nd percentile values, respectively, derived from the set of normal ECGs. Appendix A gives a set of tables with normal limits for all parameters that are used in the program criteria.

The "and" and "or" operations in the should be applied to (sub)criteria has to be specified. As a rule, when going over the criteria from right to left, an "and" or "or" that is encountered should immediately be applied to the (sub)criteria adjacent to it.

1.6 References

PEDMEANS is based on the Modular ECG Analysis System (MEANS) which has been developed for computerized interpretation of adult ECGs. The main difference between PEDMEANS and MEANS is their diagnostic logic which had to be completely redesigned for PEDMEANS. In several publications, the program structure and signal analysis part of PEDMEANS and 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.

An initial report about the establishment of the normal limits used in PEDMEANS is provided in:

- Rijnbeek PR, Witsenburg M, Schrama E, Kors JA. A new standard for the juvenile electrocardiogram [abstract]. J Am Coll Cardiol 1999;33 Suppl:534A.

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)
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 amplitude quantities are given in 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).
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).
RS ratio	Ratio of the maximum amplitudes of R and S waves.
S amplitude	Maximum amplitude of the S wave (in µV).
S duration	Duration of the S wave (in ms).
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 Wolf-Parkinson-White syndrome (WPW)

Due to the anomalous conduction pathway (Kent bundle), the corresponding ventricle is depolarized at a slower rate through the ventricular myocardium. This produces initial slurring (delta wave), a short PR interval and wide QRS complex. The presence of delta waves in two or more leads is a necessary condition for the diagnosis of WPW. Only if delta waves are found in two or more leads, together with a short PR interval or a wide QRS complex, a definite diagnosis of WPW is made.

Say: "WPW"
if: delta wave in at least 2 leads
and PR interval > ULN
or QRS duration > ULN

Say: "possible WPW"
if: delta wave in at least 2 leads

If the test WPW passed, no further contour analysis is performed.

2.3 Left bundle branch block (LBBB)

In LBBB the septal depolarization proceeds leftward from the right ventricle, resulting in a loss of the Q wave in I and/or V6. The left ventricle is depolarized through the ventricular myocardium at a much slower rate, producing prolongation of the QRS duration for age. The axis of the QRS complex is directed to the left and posteriorly, resulting in wide R waves in I, V6, and V7, and wide S waves in V1, V2, and V3R. The duration criteria should be fulfilled in at least three leads to produce the statement “LBBB.”

The diagnosis “probable LBBB” will be made if Q waves are found in I and V6.

Because LBBB is rare in very young children, only possible LBBB statements are made below one month.

Skip tests
if: QRS duration ≤ ULN + 10 ms
Say: “LBBB”
if: no Q wave in 1 of I, V6
and three or more leads with
R duration > ULN in I, V6, V7
or S duration > ULN in V1, V2, V3R
and age > 30 days

Say: “probable LBBB”
if: three or more leads with
R duration > ULN in I, V6, V7
or S duration > ULN in V1, V2, V3R
and age > 30 days

Say: “possible LBBB”
if: three or more leads with
R duration > ULN in I, V6, V7
or S duration > ULN in V1, V2, V3R
and age ≤ 30 days

2.4 Right bundle branch block (RBBB)

In RBBB, the right ventricle (RV) is not depolarized directly through the Purkinje system. Thus, the RV depolarizes through the ventricular myocardium at a much slower rate due to the slower conduction velocity. This results in a sequential depolarization of the ventricles. Because the right ventricle is located in the right and anterior part of the myocardial mass, the terminal slow depolarization is directed rightward and anteriorly. This is manifested in the ECG by wide and slurred R′ waves in V1, V3R, and aVR and wide and slurred S waves in I, II, V6, and V7. The QRS duration is longer than normal for age. In the decision rule, the duration of the second half of depolarization should be at least twice as long as the duration of the first half. The duration criteria should be fulfilled in at least three leads to make an RBBB statement.

If the R′ wave in V1 is absent, the statement “probable RBBB” is made.

Skip tests
if: QRS duration ≤ ULN

prolonged R′: R′ duration > ULN
and R′ duration > 2 * S duration
and R′ amplitude > R amplitude
prolonged S: S duration > ULN
and S duration > 2 * R duration

Say: “RBBB”
if: R′ wave in V1
and three or more leads with
prolonged R′ in V3R, V1, aVR
or prolonged S in I, II, V6, V7

Say: “probable RBBB”
if: three or more leads with
prolonged R′ in V3R, V1, aVR
or prolonged S in I, II, V6, V7

2.5 Intraventricular conduction delay

A statement of intraventricular conduction delay will only be made in the absence of RBBB, LBBB, and WPW. Different grades of severity are distinguished.

Say: "slight intraventricular conduction delay"
if: ULN < QRS duration ≤ ULN + 15 ms

Say: "moderate intraventricular conduction delay"
if: ULN + 15 ms < QRS duration ≤ ULN + 30 ms

Say: "marked intraventricular conduction delay"
if: ULN + 30 ms < QRS duration ≤ ULN + 60 ms

Say: "very marked intraventricular conduction delay"
if: QRS duration > ULN + 60 ms

2.6 Atrial hypertrophy (AH)

The diagnosis of right atrial hypertrophy (RAH) or left atrial hypertrophy (LAH) is considered in the presence of a normal P axis. Otherwise, an unusual P axis is reported.

Atrial hypertrophy results in increased amplitude and/or duration of the P waves. In RAH, or "P-pulmonale," a tall P wave in any lead is expected. LAH, or "P-mitrale," produces prolongation of the P duration, sometimes associated with notched P waves. Often the P wave in V3R, V1, or V2 is biphasic with a negative prolonged terminal part.

For RAH, P-amplitude criteria are different for children younger and older than one month.

Say: "unusual P axis"
if: P axis ≤ –30
or P axis > 90

Say: "LAH"
if: P duration > ULN
and negative P amplitude > 100 μV in 1 of V3R, V1, V2
or P notch in any lead
and no unusual P axis

Say: "RAH"
if: positive P amplitude > 225 μV in any lead
and age > 30 days
or positive P amplitude > 300 μV in any lead
and age ≤ 30 days
and no unusual P axis

2.7 Axis deviation

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

Say: “right axis deviation”
if: ULN < QRS axis ≤ ULN + 20°

Say: “marked right axis deviation”
if: ULN + 20° < QRS axis ≤ ULN + 60°

Say: “extreme right inferior axis deviation”
if: ULN + 60° < QRS axis ≤ 180°

Say: “left axis deviation”
if: LLN – 45° ≤ QRS axis < LLN

Say: “marked left axis deviation”
if: LLN – 120° ≤ QRS axis < LLN – 45°

Say: “extreme left superior axis deviation”
if: –180° ≤ QRS axis < LLN – 120°

2.8 Low QRS voltage

Say: “low voltage in extremity leads”
if: positive QRS amplitude + negative QRS amplitude ≤ 500 µV in all extremity leads

Say: “low voltage in precordial leads”
if: positive QRS amplitude + negative QRS amplitude ≤ 1000 µV in all precordial leads

Say: “low voltage”
if: both previous tests passed

2.9 QT abnormalities

The QT interval is measured from the overall onset of the QRS complex to the end of the T wave. In case of intraventricular conduction delay, the QRS duration in excess of ULN is subtracted from the measured QT. A correction is made for the heart rate, using Bazett's formula: corrected QT (QTc) interval = QT interval * √(heart rate/60). The QTc interval renders the QT interval for a standard heart rate of 60 beats per minute.

Say: “short QTc interval”
if: corrected QT interval < LLN – 20 ms

Say: “long QTc interval”
if: corrected QT interval > ULN + 20 ms

Say: “high voltage”
if: 330 ≤ corrected QT interval < 470 ms
and positive T amplitude > ULN in V4, V6, V7

2.10 Left ventricular hypertrophy (LVH)

In LVH, the voltage of the QRS complex in the leads that reflect the left ventricle (LV) is increased. In the frontal plane the LV lies to the left and inferiorly, in the horizontal plane to the left and posteriorly. Therefore, an increase in voltage of the R wave is found in I, II, aVF, V6, and V7, while the S amplitude is increased in V3R, V1, and V2. However, due to cancellation of opposing electromotive forces only changes in the RS ratio may be observed. A decrease in RS ratio in V3R, V1, and V2, suggests LVH. The most reliable sign of LVH is an asymmetric T-wave inversion or “strain” pattern in I, II, aVL, aVF, V6, and V7. If LVH characteristics are found both in left and right precordial leads (mirror image), the certainty of LVH increases.

In the program logic, two types of parameters are used: voltage and repolarization. For the voltage parameter, points are accumulated according to the degree of voltage abnormality of the positive QRS amplitude in I, II, aVF, V6, and V7, and the negative QRS amplitude in V3R, V1, and V2. Three degrees of abnormality are distinguished:

“minor”: ULN < QRS amplitude < ULN + 150 µV
“moderate”: ULN + 150 µV < QRS amplitude < ULN + 300 µV
“major”: QRS amplitude > ULN + 300 µV

For each lead, the “minor”, “moderate”, and “major” degrees increase the voltage parameter by 1, 2, and 3 points, respectively.

For the repolarization parameter, the program tests for the presence and degree of ST depression and T negativity in leads I, II, aVL, aVF, V6, and V7. Strain scores are determined using the J- and T-wave amplitudes.

No definite LVH statements are made below one month.

Say: “LVH”
if: voltage parameter ≥ 8
or strain
and voltage parameter ≥ 3
or moderate strain
and voltage parameter ≥ 4
or moderate strain in 1 of V6, V7
and voltage parameter ≥ 2
or positive QRS amplitude > ULN in V6
and negative QRS amplitude > ULN in V1

Say: “probable LVH”
if: voltage parameter ≥ 6
or strain
and voltage parameter ≥ 2
or moderate strain
and voltage parameter ≥ 3
or moderate strain in 1 of V6, V7
and voltage parameter ≥ 1
or positive QRS amplitude > ULN in 1 of V6, V7
and negative QRS amplitude > ULN in 1 of V3R, V1, V2

Say: “possible LVH”
if: voltage parameter ≥ 4
or strain
and voltage parameter ≥ 1
or moderate strain
and voltage parameter ≥ 2
or positive QRS amplitude > ULN in 1 of V6, V7
and negative QRS amplitude > ULN in 1 of V3R, V1, V2
or RS ratio < LLN in 1 of V3R, V1, V2
or positive QRS amplitude > ULN in V6, V7
or negative QRS amplitude > ULN in V3R, V1

2.11 Right ventricular hypertrophy (RVH)

In RVH, the voltage of the QRS complex in the leads that reflect the right ventricle (RV) is increased, and the QRS axis is usually directed rightward. The RV occupies the right and anterior part of the ventricular mass. Therefore, an increase in voltage of the R wave is found most prominent in V1, while the S amplitude is increased in V6. However, due to cancellation of opposing electromotive forces only changes in the RS ratio may be apparent. An increase in RS ratio in V1, and a decrease in RS ratio in V6 suggest RVH. A qR pattern or pure R in V3R or V1 is strongly suggestive for RVH. From 3 days up to 6 years an upright T-wave in V1 and V6 indicates RVH. Severe RVH is often associated with repolarization disturbances (strain) in V3R, V1, and V2.

In the program, the degree of voltage abnormality and the presence of a mirror image determine the severity of RVH. In the repolarization parameter the program tests for the presence and degree of ST depression and T negativity in the leads V3R, V1, and V2. Strain scores are determined using the J- and T-wave amplitudes.

For children below one month of age, the severity score is decreased by one point, because the normal right-ventricular dominance in this age group makes the diagnosis of RVH difficult.

In the presence of a bundle branch block, the RVH tests will be skipped.

Skip tests
if: RBBB
or LBBB

Say: “RVH”
if: positive QRS amplitude in 1 of V3R, V1 > ULN + 200 µV
and negative QRS amplitude in V6 > ULN + 200 µV
or RS ratio in V6 < 0.8
or positive QRS amplitude in V1 > ULN + 200 µV
and upright T in V1, V6
and 3 days < age < 6 years
or positive QRS amplitude in V1 > ULN
and strain in 1 of V3R, V1, V2
or pure R or qR pattern in V1
and positive QRS amplitude in 1 of V3R, V1 > ULN + 200 µV
or negative QRS amplitude in V6 > ULN + 200 µV
or RS ratio in V6 < 0.8
or strain in 1 of V3R, V1, V2
or pure R or qR pattern in V3R
and RS ratio in V1 > 1.0
and positive QRS amplitude in 1 of V3R, V1 > ULN + 200 µV
or negative QRS amplitude in V6 > ULN + 200 µV
or RS ratio in V6 < 0.8
or strain in 1 of V3R, V1, V2

Say: “probable RVH”
if: positive QRS amplitude in1 of V3R, V1 > ULN
or RS ratio in V1 > ULN
and negative QRS amplitude in V6 > ULN
or RS ratio in V6 < 1.0
or positive QRS amplitude in V1 > ULN
and upright T in V1, V6
and 3 days < age < 6 years
or positive QRS amplitude in 1 of V3R, V1 > ULN
and moderate strain in 1 of V3R, V1, V2
or positive QRS amplitude in V1 > ULN + 200 µV
and RS ratio in V6 < 1.0
or negative QRS amplitude in V6 > ULN + 200 µV
and RS ratio in V1 > 1.0

or pure R or qR pattern in V3R, V1
or positive QRS amplitude in V3R, V1 > ULN
or pure R or qR pattern in V1
and positive QRS amplitude in 1 of V3R, V1 > ULN
or negative QRS amplitude in V6 > ULN
or RS ratio in V6 < 1.0
or right axis deviation
or moderate strain in 1 of V3R, V1, V2
or pure R or qR pattern in V3R
and RS ratio in V1 > 1.0
and positive QRS amplitude in 1 of V3R, V1 > ULN
or negative QRS amplitude in V6 > ULN
or RS ratio in V6 < 1.0
or right axis deviation
or moderate strain in 1 of V3R, V1, V2

Say: "possible RVH"
if: positive QRS amplitude in V1 > ULN
and right axis deviation
or negative QRS amplitude in V6 > ULN
and RS ratio in V6 < 0.66
and right axis deviation
or upright T in V1,V6
and 3 days < age < 6 years
or pure R or qR pattern in 1 of V3R, V1
or positive QRS amplitude in V1 > ULN + 200 µV
or negative QRS amplitude in V6 > ULN + 200 µV
or moderate strain in 1 of V3R, V1, V2

2.12 Biventricular hypertrophy (BVH)

Many forms of congenital heart disease produce overload of both ventricles, with resulting biventricular hypertrophy. When the criteria for both RVH and LVH are met, the diagnosis of BVH is clear-cut. However, large equiphasic QRS complexes in mid-precordial leads (Katz-Wachtel phenomenon) are also suggestive, even in the absence of any clear RVH and LVH.

The severity of BVH is determined by the severity of RVH and LVH, and the size of the equiphasic QRS complexes. Lead V4 is most important in the detection of equiphasic QRS complexes.

Say: "BVH"
(suppress RVH and LVH)
if: RVH ≥ probable
and LVH ≥ probable
or large equiphasic QRS in V4
and large equiphasic QRS in 1 of V2, V6

Say: "probable BVH"
(suppress RVH and LVH)
if: equiphasic QRS in V4
and equiphasic QRS in V2, V6

Say: "possible BVH"
(suppress RVH and LVH)
if: RVH = possible
and LVH = possible

Say: "consider BVH"
if:
RVH ≥ probable
and LVH = possible
(suppress LVH)
or LVH ≥ probable
and RVH = possible
(suppress RVH)
or large equiphasic QRS in V4
or large equiphasic QRS in V2, V6

2.13 Myocardial infarction

The diagnosis of myocardial infarction is largely based on the duration of Q waves and the presence of QS patterns. The localization of the infarct is determined by the leads in which the abnormalities are found.

Because infarcts in children are very rare and difficult to diagnose, only “possible” infarct statements are made. No infarct statements are made in the presence of hypertrophy or LBBB.

Skip tests
if: hypertrophy
or LBBB

Say: “possible inferior infarct”
if: Q duration > 35 ms and Q amplitude > 100 µV in II, III, aVF

Say: “possible anteroseptal infarct”
if: QS pattern in V1
and Q amplitude > 100 µV in V2

Say: “possible anterior infarct”
if: no Q wave in V1
and Q duration > 35 ms and Q amplitude > 100 µV in V2, V4
or QS pattern and Q amplitude > 100 µV in 3 of all precordial leads

Say: “possible anterolateral infarct”
if: Q duration > 35 and Q amplitude > 100 µV in V4, V6

Say: “possible highlateral infarct”
if: Q duration > 35 ms and Q amplitude > 100 µV in I, aVL

2.14 ST elevation

Say: "inferior ST elevation"
if: J amplitude > ULN + 50 µV in aVF
and J amplitude > ULN in 1 of II, III

Say: "highlateral ST elevation"
if: J amplitude > ULN + 50 µV in I, aVL

Say: "right-precordial ST elevation"
if: J amplitude > ULN + 50µV in 1 of V3R, V1
and J amplitude > ULN in V2

Say: "mid-precordial ST elevation"
if: J amplitude > ULN + 50 µV in V2
and J amplitude > ULN in V4, V6

Say: "left-precordial ST elevation"
if: J amplitude > ULN + 50 µV in V6, V7

2.15 ST depression

Say: "inferior ST depression"
if: J amplitude < LLN – 50 µV in aVF
and J amplitude < LLN in 1 of II, III

Say: "highlateral ST depression"
if: J amplitude < LLN – 50 µV in I, aVL

Say: "right-precordial ST depression"
if: J amplitude < LLN – 50 µV in 1 of V3R, V1
and J amplitude < LLN in V2

Say: "mid-precordial ST depression"
if: J amplitude < LLN – 50 µV in V2
and J amplitude < LLN in V4, V6

Say: "left-precordial ST depression"
if: J amplitude < LLN – 50 µV in V6, V7

2.16 Repolarization

Negative T waves are classified in one of the following categories:

“flat”:	positive T amplitude < 50 μV and negative T amplitude ≤ 50 μV
“(abnormal) small negative”:	ULN + 50 < negative T amplitude ≤ ULN + 100 μV
“(abnormal) negative”:	ULN + 100 < negative T amplitude ≤ ULN + 250 μV
“large negative”:	ULN + 250 < negative T amplitude ≤ ULN + 500 μV
“very large negative”:	negative T amplitude > ULN + 500 μV

Using this negative T-wave classification, repolarization statements can be made for five different localizations: “inferior” (II, III, aVF), “highlateral” (I, aVL), “right precordial” (V3R, V1), “mid precordial” (V2, V4), and “left precordial” (V6, V7). Because normal T waves can be negative in V3R, V1, and V2, the ULN of the negative T wave is used. In the other leads the ULN is zero. The severity of a repolarization disturbance is indicated by one of six possible grades: “minimal”, “minor”, “slight”, “moderate”, “strong”, “very strong”. 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 strong <loc> repolarization disturbance”, where <loc> denotes one of the five localizations mentioned above, requires a very 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 “strong <loc> repolarization disturbance” requires a large negative T wave in at least one of the relevant leads. Statements for “moderate”, “slight”, and “minimal” repolarization disturbances 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.

Additionally, the program looks for mainly positive T in the right-precordial leads, for children aged 3 days up to 6 years.

Say:	“right precordial repolarization disturbance”
if:	positive T amplitude – negative T amplitude > 100 μV in 1 of V3R, V1
and	3 days < age < 6 years

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, the program may append one of the following statements:

“secondary to LVH”
“secondary to RVH”
“secondary to RBBB”
“secondary to LBBB”
“secondary to infarct”
“compatible with early repolarization”

2.17 Combination of statements

If repolarization disturbances at different localizations have been detected, the program tries to combine separate localizations in one statement. When “right precordial”, “mid precordial”, and “left precordial” repolarization disturbances are present together, the statement “extensive precordial repolarization disturbance” is made.

If infarction is present at different locations, the program attempts to generate a combined infarction statement. The following combinations can be made:

“inferior”+“lateral”	→ “inferolateral”
“anterior”+“lateral”	→ “anterolateral”
“anterior”+“septal”	→ “anteroseptal”
“anterior”+“septal”+“lateral”	→ “extensive anterior”
“anterior”+“septal”+“lateral”+“high lateral”	→ “extensive anterior and highlateral”

3 Rhythm analysis

3.1 Introduction

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

1 The first aim of the computer program 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 are 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 program checks which relation 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 less than 15% of the QRS complexes is preceded by a P wave. This criterion has been built in to make allowance for the program detecting P waves by mistake.
- Some QRS complexes are preceded by a P wave, others are not. This category will be chosen if 15-90% of the QRS complexes are preceded by a P wave.
- 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 constancy of the RR interval, P/QRS ratio, and constancy of the PR interval are not the only characteristics on 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 over a hundred and fifty statements concerning the type of rhythm.

Subsequent paragraphs in this chapter will describe the parameters that are used in rhythm analysis, the general structure of the decision tree and 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 diagnostic criteria of the rhythm section:

- P/QRS ratio: ratio of the number of P waves to the number of dominant QRS complexes. Used as a measure for atrial activity.
- PR range: difference between the maximum and minimum PR interval (in ms). 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 type of QRS complex and non-dominant types. 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).
- V rate: number of ventricular contractions (in BPM)
- rate variation: difference between the maximum and minimum RR interval, normalized to the average RR interval. Used as a measure for regularity of the rhythm.
- QRS duration: difference between the overall 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. 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 case of pacemaker spikes or flutter waves an appropriate statement is issued and the rhythm analysis stops. In case 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 (dominant complexes) is analyzed.

Second, regular rhythms are distinguished from irregular ones based on the constancy of the RR interval. Both types of rhythm are subdivided in different groups depending on the number of P waves as compared to the number of QRS complexes (P/QRS ratio) and on the constancy of the PR interval (PR range). It may happen that the irregularity of a rhythm is 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 complexes, is regular the rhythm is taken care of 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 $\leq$ 0.15
5	Regular rhythms with 0.15 < P/QRS $\leq$ 1.0 and PR range > 60 ms
6	Regular rhythms with P/QRS > 1.0 and PR range $\leq$ 30 ms
7	Regular rhythms with P/QRS > 1.0 and PR range > 30 ms
8	Irregular rhythms with P/QRS $\leq$ 0.15
9	Rhythms with paroxysmal acceleration or deceleration of the ventricular rate
10	Irregular rhythms with 0.15 < P/QRS $\leq$ 0.9 and PR range $\leq$ 30 ms
11	Irregular rhythms with 0.15 < P/QRS $\leq$ 0.9 and PR range > 30 ms
12	Irregular rhythms with 0.9 < P/QRS $\leq$ 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 $\leq$ 30 ms
15	Rhythms with constant PR interval

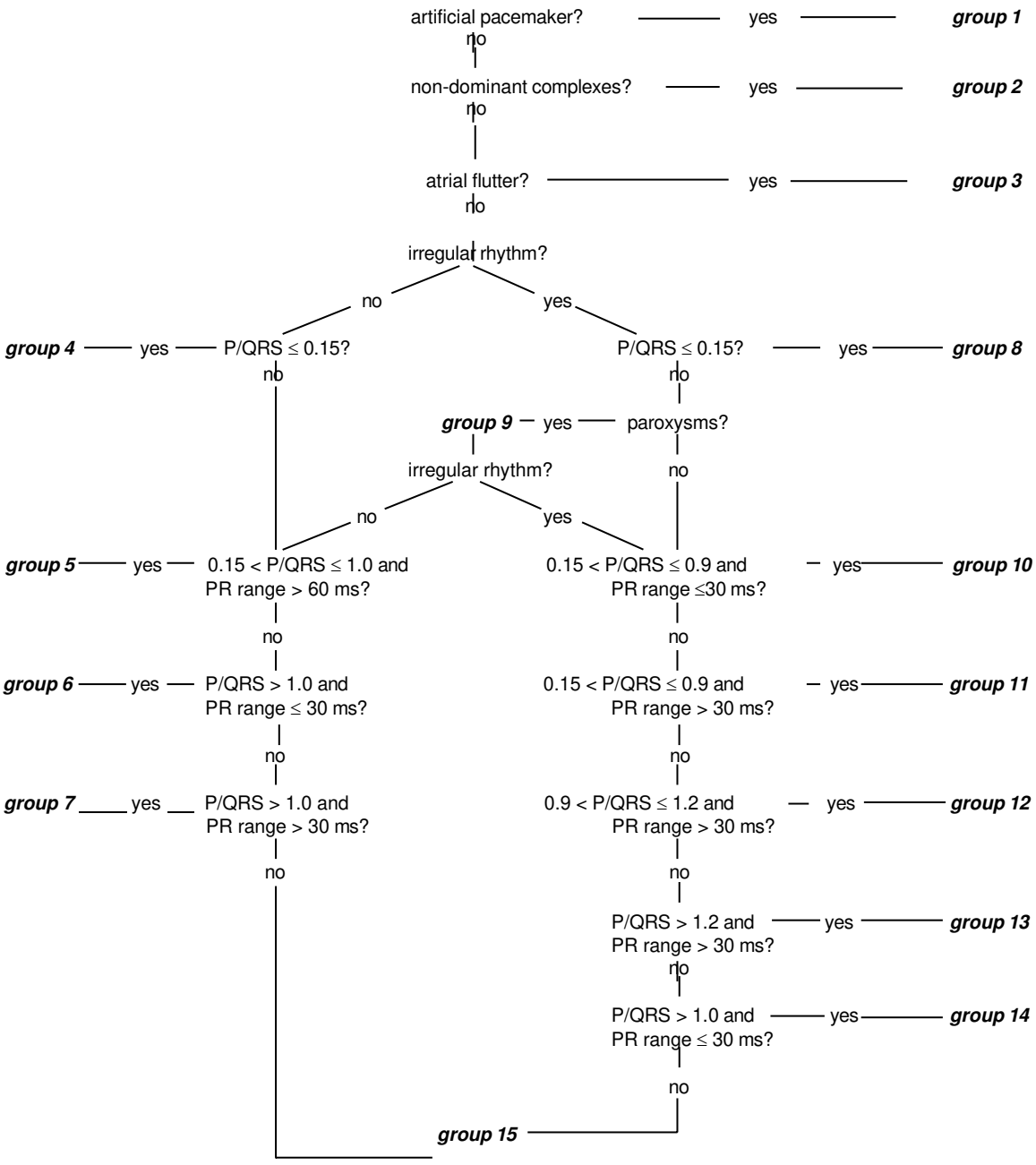

Figure 1. Structure of the decision tree for rhythm classification.

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 which 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 remaining single non-dominant complexes are classified type by type according to QRS width and 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 adaptations 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 in run

Say: “with accelerated ectopic rhythm”
if: one type of non-dominant complexes in run
and run rate ≤ ULN

Say: “with supraventricular tachycardia with aberrant ventricular conduction,”
“ consider ventricular tachycardia”
if: one type of non-dominant complexes in run
and run rate > ULN
and QRS duration in run ≤ ULN + 20 ms

Say: “with (probably) ventricular tachycardia, consider supraventricular”
“ tachycardia with aberrant ventricular conduction”
if: one type of non-dominant complexes in run
and run rate > ULN
and QRS duration in run > ULN + 20 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

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
and QRS duration non-dominant complexes ≤ ULN + 20 ms
and RR ratio > 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
and QRS duration non-dominant complexes > ULN + 20 ms
and RR ratio > 1.2

Say: “doublets of aberrantly conducted complexes”
or
“sequence of aberrantly conducted complexes”
if: one type of non-dominant consecutive complexes
and 0.9 < RR ratio ≤ 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
and QRS duration non-dominant complexes ≤ ULN + 20 ms
and RR ratio ≤ 0.9

Say: “doublets of premature ventricular complexes”
or
“sequence of ventricular complexes”
if: one type of non-dominant consecutive complexes
and QRS duration non-dominant complexes > ULN + 20 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 ≤ ULN + 20 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 > ULN + 20 ms
and coupling interval range > 80 ms

Say: “multiform premature ventricular complexes”
or
“premature ventricular complexes”
if: QRS duration non-dominant complexes > ULN + 20 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 ≤ ULN
and coupling interval range > 80 ms

Say: “supraventricular escapes with aberrant ventricular conduction,”
“ cause? eg SA block? ”
if: QRS duration non-dominant complexes ≤ ULN
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 ≤ ULN
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: ULN < QRS duration non-dominant complexes ≤ ULN + 20 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 ≤ ULN + 20 ms
and coupling interval range ≤ 80 ms
and RR ratio ≤ 0.9

Say: “ventricular escapes or supraventricular escapes with”
“ aberrant ventricular conduction, cause?”
if: ULN < QRS duration non-dominant complexes ≤ ULN + 20 ms
and coupling interval range ≤ 80 ms
and RR ratio > 1.2

Adaptation of statements

The program classifies the non-dominant complexes before it classifies the rhythm, assuming both classifications do not interfere. However, in the presence of atrial fibrillation, atrial flutter, atrial tachycardia, second degree AV block, or advanced AV block a detailed classification of 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 > 30%

Say: "with second degree AV block at N:1 conduction ratio"
if: rate variation ≤ 30%
and atrial rate is an integer multiple N of ventricular rate

Say: "with complete AV block"
if: rate variation ≤ 30%
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 ≤ 30%
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 270 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 < 270 ms
and rate variation ≤ 30%

Say: "atrial flutter with second degree AV block at variable conduction ratio"
if: shortest PP interval < 270 ms
and rate variation > 30%

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

Say: “idioventricular rhythm (no atrial activity detected)”
if: QRS duration ≥ ULN + 20 ms
and heart rate < LLN – 20 BPM

Say: “AV junctional rhythm with aberrant ventricular conduction or”
“ accelerated idioventricular rhythm (no atrial activity detected)”
if: QRS duration ≥ ULN + 20 ms
and LLN – 20 BPM ≤ heart rate < LLN

Say: “accelerated AV junctional rhythm with aberrant ventricular conduction or”
“ accelerated idioventricular rhythm (no atrial activity detected)”
if: QRS duration ≥ ULN + 20 ms
and LLN ≤ heart rate < ULN

Say: “AV junctional tachycardia with aberrant ventricular conduction,”
“ consider ventricular tachycardia (no atrial activity detected) ”
if: QRS duration ≥ ULN + 20 ms
and ULN ≤ heart rate < ULN + 20 BPM

Say: “supraventricular tachycardia with aberrant ventricular conduction,”
“ consider ventricular tachycardia ”
if: QRS duration ≥ ULN + 20 ms
and ULN + 20 BPM ≤ heart rate < ULN + 40 BPM

Say: “supraventricular tachycardia with aberrant ventricular conduction,”
“ consider ventricular tachycardia ”
if: QRS duration ≥ ULN + 20 ms
and ULN + 40 ≤ heart rate < 200 BPM

Say: “supraventricular tachycardia with aberrant ventricular conduction and”
“ very high ventricular rate, or ventricular tachycardia”
if: QRS duration ≥ ULN + 20 ms
and heart rate ≥ 200 BPM

Say: “AV junctional rhythm (no atrial activity detected)”
if: QRS duration < ULN + 20 ms
and heart rate < LLN

Say: “accelerated AV junctional rhythm (no atrial activity detected)”
if: QRS duration < ULN + 20 ms
and LLN ≤ heart rate < ULN

Say: “AV junctional tachycardia (no atrial activity detected)”
if: QRS duration < ULN + 20 ms
and LLN ≤ heart rate < ULN + 20 BPM

Say: “supraventricular tachycardia, consider atrial flutter”
“with 2:1 A-V conduction”
if: QRS duration < ULN + 20 ms
and ULN + 20 BPM ≤ heart rate < ULN + 40 BPM

Say: “supraventricular tachycardia (atrial flutter or atrial tachycardia)”
if: QRS duration < ULN + 20 ms
and ULN + 40 BPM ≤ heart rate < 200 BPM

Say: “supraventricular tachycardia with very high ventricular rate”
if: QRS duration < ULN + 20 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 < LLN – 20 BPM
and QRS duration ≥ ULN + 20 ms

Say: "sinus rhythm with complete AV block; accelerated idioventricular escape rhythm,"
" consider AV junctional rhythm with aberrant ventricular conduction"
if: LLN – 20 BPM ≤ heart rate < LLN
and QRS duration ≥ ULN + 20 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: LLN ≤ heart rate < ULN
and QRS duration ≥ ULN + 20 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 ≥ ULN
and QRS duration ≥ ULN + 20 ms

Say: "sinus rhythm with complete AV block; AV junctional escape rhythm"
if: heart rate < LLN
and QRS duration < ULN + 20 ms

Say: "sinus rhythm with block and/or interference in the AV junction;"
" accelerated AV junctional rhythm "
if: LLN ≤ heart rate < ULN
and QRS duration < ULN + 20 ms

Say: "supraventricular tachycardia with block and/or interference in the AV junction"
if: ULN ≤ heart rate < ULN + 40 BPM
and QRS duration < ULN + 20 ms

Say: "supraventricular tachycardia, consider atrial flutter with"
" second degree AV block at 2:1 conduction ratio"
if: heart rate ≥ ULN + 40 BPM
and QRS duration < ULN + 20 ms

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

Say: “atrial flutter”
if: shortest PP interval < 270 ms

Say: “atrial tachycardia”
if: 270 ≤ shortest PP interval < 370 ms

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

Say: “sinus rhythm”
if: shortest PP interval > ULN

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: 270 ≤ shortest PP interval < 370 ms

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

Say: "sinus rhythm"
if: shortest PP interval ≥ LLN

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 ≥ ULN + 20 ms
and heart rate < LLN – 20 BPM

Say: "with complete AV block"
"accelerated idioventricular escape rhythm, consider"
"AV junctional rhythm with aberrant ventricular conduction"
if: QRS duration ≥ ULN + 20 ms
and LLN – 20 BPM ≤ heart rate < LLN

Say: "with block and/or interference in the AV junction"
"accelerated AV junctional rhythm with aberrant ventricular conduction,"
"consider ventricular tachycardia"
if: QRS duration ≥ ULN + 20 ms
and LLN ≤ heart rate < ULN

Say: "with block and/or interference in the AV junction"
"AV junctional tachycardia with aberrant ventricular conduction,"
"consider ventricular tachycardia"
if: QRS duration ≥ ULN + 20 ms
and heart rate ≥ ULN

Say: "with complete AV block"
"AV junctional escape rhythm"
if: QRS duration < ULN + 20 ms
and heart rate < LLN

Say: "with block and/or interference in the AV junction"
"accelerated AV junctional rhythm"
if: QRS duration < ULN + 20 ms
and LLN ≤ heart rate < ULN

Say: "with block and/or interference in the AV junction"
"AV junctional tachycardia"
if: QRS duration < ULN + 20 ms
and heart rate ≥ ULN

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

Say: "atrial fibrillation with slow mean ventricular response"
if: heart rate < LLN – 10 BPM

Say: "atrial fibrillation with normal mean ventricular response"
if: LLN – 10 BPM ≤ heart rate < ULN

Say: "atrial fibrillation with rapid mean ventricular response"
if: ULN ≤ heart rate < ULN + 80 BPM

Say: "atrial fibrillation with very rapid mean ventricular response"
if: heart rate ≥ ULN + 80 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 < ULN + 40 BPM

Say: "with episode of paroxysmal junctional tachycardia"
if: there is a run
and ULN + 40 < run rate ≤ ULN + 60 BPM

Say: "with episode of paroxysmal atrial tachycardia"
if: there is a run
and run rate > ULN + 60 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 < LLN – 10 BPM

Say: "consider supraventricular escapes, cause? eg AV block, SA block?"
if: 30 < PR range ≤ 60 ms
and heart rate < LLN – 10 BPM

Say: "premature atrial complexes"
if: 60 < PR range ≤ 120 ms
and heart rate ≥ LLN – 10 BPM

Say: "consider premature atrial complexes"
if: 30 < PR range ≤ 60 ms
and heart rate ≥ LLN – 10 BPM

Say: "sinus bradycardia"
if: heart rate < LLN – 10 BPM

Say: "sinus rhythm"
if: LLN – 10 BPM ≤ heart rate < ULN

Say: "sinus tachycardia"
if: heart rate ≥ ULN

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 < LLN – 10 BPM

Say: "sinus rhythm"
if: LLN – 10 BPM ≤ heart rate < ULN

Say: "sinus tachycardia"
if: heart rate ≥ ULN

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: 270 ≤ shortest PP interval < LLN

Say: “sinus rhythm with second degree AV block at variable conduction ratio”
if: shortest PP interval ≥ LLN

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 < 270 ms

Say: “atrial tachycardia”
if: 270 ≤ shortest PP interval < 370 ms

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

Say: “sinus rhythm”
if: shortest PP interval ≥ LLN

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 limit used for the PR interval is normalized for heart rate (normalized PR = PR interval / RR interval).

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

Say: “PR interval variation: pacemaker shift?”
if: 30 < PR range ≤ 60 ms
and P/QRS ≤ 0.9

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

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

Say: “sinus bradycardia with sinus arrhythmia”
if: heart rate < LLN – 10 BPM
and rate variation > 30%

Say: “sinus arrhythmia”
if: LLN – 10 BPM ≤ heart rate < ULN
and rate variation > 30%

Say: “sinus tachycardia with sinus arrhythmia”
if: heart rate ≥ ULN
and rate variation > 30%

Say: “extreme bradycardia, consider sinus rhythm with 2:1 AV conduction”
if: heart rate < LLN – 20 BPM
and rate variation ≤ 30%

Say: “sinus bradycardia”
if: LLN – 20 BPM ≤ heart rate < LLN – 10 BPM
and rate variation ≤ 30%

Say: “sinus rhythm (slow)”
if: LLN – 10 BPM ≤ heart rate < LLN
and rate variation ≤ 30%

Say: “sinus rhythm”
if: LLN ≤ heart rate < ULN – 10 BPM
and rate variation ≤ 30%

Say: “sinus rhythm (rapid)”
if: ULN – 10 BPM ≤ heart rate < ULN
and rate variation ≤ 30%

Say: “sinus tachycardia”
if: heart rate ≥ ULN
and rate variation ≤ 30%

Say: “short PR interval”
if: normalized PR interval < LLN
and heart rate < 140 BPM

Say: “first degree AV block (limited)”
if: ULN < normalized PR interval ≤ ULN + 0.025

Say: “first degree AV block”
if: normalized PR interval > ULN + 0.025

4 The Performance of PEDMEANS

PEDMEANS is based on the Modular ECG Analysis System (MEANS), which was developed for the interpretation of adult ECGs. Development of PEDMEANS 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. This report describes the performance of PEDMEANS (version DI.AO) contour analysis module on the contour databases.

Methods

The diagnostic performance of the system has been evaluated using a database of normal and abnormal pediatric electrocardiograms. The database consists of 642 ECGs collected at the Sophia Children's Hospital in Rotterdam, The Netherlands. Two pediatric cardiologists interpreted all ECGs using a computerized overreading form. The certainty of each abnormality could be expressed using the qualifiers absent (=0), possible (=1), probable (=2), and definite (=3). When the interpretations of the two pediatric cardiologists differed by one point, one of both interpretations was randomly selected as the reference final interpretation. When the interpretation differed by two or more qualifier points, a third pediatric cardiologist adjudicated the ECG. This interpretation was then taken as the reference. Four clinically relevant categories have been evaluated: left ventricular hypertrophy (LVH), right ventricular hypertrophy (RVH), left bundle branch block (LBBB), and right bundle branch block (RBBB).

PEDMEANS contour diagnostic database

The contour diagnostic database consists of 642 ECGs, divided over five categories: normal (NOR), left ventricular hypertrophy (LVH), right ventricular hypertrophy (RVH), left bundle branch block (LBBB), and right bundle branch block (RBBB). All 642 ECGs were processed by PEDMEANS using PEDMEANS (version DI.AO). Diagnostic statements produced by PEDMEANS were categorized as prescribed by the thesis [1, p. 75]. These statements were compared with the cardiologist reference statements. Classification matrices and summary statistics are documented below.

Results

Contour recognition

Table 1. Accuracy of diagnostic interpretative statements on the contour diagnostic database vs. Cardiologist reference.

Diagnostic Category	No. of ECGs tested	Sensitivity; %	Specificity: %	Positive predictive value %	Comments
LVH	151	76.5	95.4	51.0	
RVH	174	64.9	95.8	66.7	
LBBB	6	100.0	99.7	66.7	
RBBB	94	80.0	93.6	51.3	

References

1. Rijnbeek, Peter R. Automatic Interpretation of Pediatric Electrocardiograms. Thesis Erasmus University Rotterdam The Netherlands, 2007.

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Appendix A Normal limits

The following tables show normal limits for the ECG parameters as approximations of the continuous age-dependent normal limits, which are used in the classification part of PEDMEANS. Figures denote mean and, in parentheses, upper limit of normal (ULN) and lower limit of normal (LLN) (the latter only if diagnostically relevant).

Lead-independent parameters

Table 2. Lead-independent parameters: Mean (LLN, ULN)

	0-1 mo	1-3 mo	3-6 mo	6-12 mo	1-3 yr	3-5 yr	5-8 yr	8-12 yr	12-16 yr
Heart rate (BPM)	163 (136, 206)	155 (126, 193)	140 (116, 178)	134 (106, 185)	126 (97, 174)	99 (77, 122)	89 (64, 113)	80 (59, 106)	75 (53, 102)
P axis (°)	52 (23, 82)	50 (12, 75)	49 (14, 77)	49 (9, 83)	47 (–4 , 89)	42 (–4, 82)	38 (–20, 74)	40 (–13, 81)	39 (–15, 82)
P duration (ms)	69 (60, 81)	75 (61, 99)	80 (66, 99)	83 (68, 102)	85 (67, 106)	88 (74, 106)	91 (74, 107)	96 (78, 120)	100 (80, 124)
PRn interval (ms)	0.26 (0.19,0.32)	0.25 (0.19,0.33)	0.25 (0.19, 0.32)	0.24 (0.17, 0.31)	0.24 (0.16, 0.31)	0.20 (0.14,0.28)	0.19 (0.12, 0.27)	0.18 (0.12,0.25)	0.17 (0.10, 0.25)
QRS axis (°)	106 (63, 149)	83 (43, 127)	67 (12, 108)	68 (21, 114)	68 (17, 118)	68 (15, 109)	70 (14, 115)	65 (3, 116)	63 (4, 107)
QRS duration (ms)	65 (79)	63 (77)	66 (80)	67 (84)	70 (87)	74 (91)	79 (96)	84 (101)	90 (109)
QTc interval (ms)	413 (369, 460)	422 (381, 471)	423 (384, 477)	419 (387, 468)	423 (390, 464)	430 (402, 457)	430 (393, 465)	428 (387, 465)	428 (379, 477)

Lead-dependent parameters

Table 3. Positive QRS amplitude (mV): Mean (ULN)

Lead	0-1 mo	1-3 mo	3-6 mo	6-12 mo	1-3 yr	3-5 yr	5-8 yr	8-12 yr	12-16 yr
I	0.31 (0.62)	0.62 (1.15)	0.79 (1.42)	0.81 (1.41)	0.76 (1.43)	0.64 (1.12)	0.58 (1.08)	0.58 (1.11)	0.56 (1.09)
II	0.73 (1.29)	1.18 (1.93)	1.31 (2.14)	1.30 (2.10)	1.33 (2.37)	1.36 (2.17)	1.35 (2.31)	1.38 (2.19)	1.30 (2.05)
III	0.83 (1.47)	0.89 (1.67)	0.90 (1.64)	0.90 (1.82)	0.92 (1.94)	0.94 (1.84)	0.96 (1.98)	0.93 (1.83)	0.86 (1.73)
aVR	0.32 (0.57)	0.31 (0.57)	0.28 (0.51)	0.27 (0.56)	0.24 (0.51)	0.21 (0.45)	0.21 (0.46)	0.19 (0.43)	0.19 (0.43)
aVL	0.19 (0.41)	0.32 (0.70)	0.42 (0.92)	0.46 (0.94)	0.43 (0.94)	0.28 (0.64)	0.23 (0.63)	0.19 (0.56)	0.19 (0.58)
aVF	0.74 (1.28)	0.99 (1.73)	1.05 (1.80)	1.04 (1.90)	1.08 (2.11)	1.13 (1.97)	1.13 (2.14)	1.14 (1.99)	1.07 (1.86)
V3R	0.67 (1.07)	0.60 (1.11)	0.57 (1.15)	0.51 (1.11)	0.49 (0.98)	0.36 (0.74)	0.25 (0.59)	0.21 (0.48)	0.20 (0.50)
V1	1.33 (2.16)	1.24 (1.99)	1.25 (2.11)	1.12 (2.05)	1.09 (1.98)	0.87 (1.61)	0.64 (1.36)	0.55 (1.12)	0.46 (1.11)
V2	1.85 (2.39)	1.85 (2.57)	1.92 (2.58)	1.84 (2.43)	1.75 (2.39)	1.48 (2.21)	1.14 (2.05)	1.00 (1.86)	0.86 (1.75)
V4	1.80 (2.41)	2.30 (3.22)	2.28 (3.21)	2.25 (3.20)	2.28 (3.40)	2.31 (3.23)	2.00 (3.11)	1.86 (3.21)	1.63 (2.98)
V6	1.05 (1.72)	1.59 (2.50)	1.67 (2.69)	1.72 (2.75)	1.75 (2.82)	1.96 (3.01)	2.04 (3.10)	2.09 (3.10)	1.85 (2.88)
V7	0.54 (0.94)	0.95 (1.56)	1.02 (1.77)	1.09 (1.81)	1.16 (1.90)	1.34 (2.08)	1.35 (2.17)	1.39 (2.15)	1.38 (2.16)

Table 4. Negative QRS amplitude (mV): Mean (ULN)

Lead	0-1 mo	1-3 mo	3-6 mo	6-12 mo	1-3 yr	3-5 yr	5-8 yr	8-12 yr	12-16 yr
I	0.47 (0.90)	0.43 (0.83)	0.37 (0.73)	0.39 (0.77)	0.33 (0.76)	0.24 (0.60)	0.24 (0.56)	0.18 (0.47)	0.17 (0.45)
II	0.26 (0.56)	0.27 (0.53)	0.28 (0.53)	0.28 (0.57)	0.27 (0.56)	0.25 (0.53)	0.25 (0.56)	0.25 (0.57)	0.26 (0.60)
III	0.19 (0.35)	0.26 (0.55)	0.32 (0.75)	0.37 (0.78)	0.35 (0.81)	0.22 (0.53)	0.20 (0.51)	0.19 (0.50)	0.20 (0.55)
aVR	0.44 (0.67)	0.83 (1.30)	0.97 (1.48)	0.97 (1.46)	0.96 (1.60)	0.94 (1.44)	0.92 (1.41)	0.95 (1.45)	0.90 (1.37)
aVL	0.58 (1.07)	0.54 (1.00)	0.47 (0.92)	0.49 (1.01)	0.46 (1.03)	0.39 (0.97)	0.41 (0.94)	0.35 (0.88)	0.32 (0.87)
aVF	0.17 (0.38)	0.20 (0.39)	0.23 (0.50)	0.25 (0.53)	0.25 (0.56)	0.20 (0.45)	0.19 (0.48)	0.20 (0.50)	0.21 (0.51)
V3R	0.21 (0.59)	0.28 (0.76)	0.36 (0.92)	0.38 (0.97)	0.48 (1.11)	0.53 (1.06)	0.56 (1.06)	0.61 (1.17)	0.57 (1.11)
V1	0.75 (1.47)	0.77 (1.60)	0.79 (1.71)	0.81 (1.82)	0.99 (2.16)	1.12 (2.06)	1.24 (2.35)	1.38 (2.49)	1.27 (2.33)
V2	1.46 (2.18)	1.48 (2.51)	1.49 (2.45)	1.55 (2.63)	1.77 (2.94)	1.98 (2.95)	2.17 (3.28)	2.28 (3.44)	2.14 (3.59)
V4	1.14 (1.79)	1.20 (1.95)	1.23 (2.23)	1.16 (2.27)	1.08 (2.08)	1.11 (2.27)	1.26 (2.51)	1.18 (2.31)	1.00 (2.05)
V6	0.50 (0.91)	0.48 (0.92)	0.47 (1.02)	0.44 (1.06)	0.39 (0.88)	0.34 (0.75)	0.36 (0.82)	0.33 (0.77)	0.36 (0.77)
V7	0.19 (0.36)	0.23 (0.43)	0.22 (0.44)	0.24 (0.50)	0.24 (0.50)	0.20 (0.38)	0.17 (0.40)	0.15 (0.37)	0.18 (0.37)

Table 5. R/S ratio: Mean (LLN, ULN)

Lead	0-1 mo	1-3 mo	3-6 mo	6-12 mo	1-3 yr	3-5 yr	5-8 yr	8-12 yr	12-16 yr
V3R	3.4 (1.2, S=0)	2.6 (0.5, S=0)	2.0 (0.2, S=0)	1.7 (0.3, S=0)	1.3 (0.2, S=0)	0.8 (0.1, S=0)	0.5 (0.1, S=0)	0.4 (0.1, S=0)	0.4 (0.0, S=0)
V1	2.3 (0.9, 5.0)	2.1 (0.5, 4.7)	2.0 (0.5, 4.3)	1.7 (0.6, 3.6)	1.3 (0.4, 2.8)	0.9 (0.3, 1.8)	0.6 (0.1, 1.5)	0.5 (0.1, 1.1)	0.4 (0.1, 1.0)
V2	1.3 (0.8, 2.3)	1.4 (0.7, 2.8)	1.4 (0.6 ,2.6)	1.3 (0.6, 2.4)	1.1 (0.4, 2.0)	0.8 (0.3, 1.5)	0.6 (0.1, 1.2)	0.5 (0.1, 1.1)	0.4 (0.1, 1.0)
V6	2.2 (0.6, S=0)	3.8 (1.2, S=0)	4.9 (0.8, S=0)	5.4 (1.4, S=0)	6.9 (0.5, S=0)	9.1 (2.2, S=0)	8.1 (1.8, S=0)	8.6 (2.1, S=0)	6.8 (1.5, S=0)
V7	3.4 (0.9, S=0)	5.2 (1.8, S=0)	5.8 (1.3, 14.6)	6.7 (1.6, S=0)	8.0 (1.3, S=0)	9.5 (2.8, S=0)	10.7 (2.3, S=0)	11.3 (2.4, S=0)	9.2 (2.1, S=0)

Table 6. T amplitude (mV): Mean (ULN of negative T, ULN of positive T)

Lead	0-1 mo	1-3 mo	3-6 mo	6-12 mo	1-3 yr	3-5 yr	5-8 yr	8-12 yr	12-16 yr
I	0.20 (0.12, 0.33)	0.22 (0.09, 0.36)	0.24 (0.08, 0.39)	0.24 (0.08, 0.40)	0.25 (0.09, 0.39)	0.26 (0.10, 0.42)	0.25 (0.14, 0.39)	0.27 (0.15, 0.42)	0.25 (0.11, 0.41)
II	0.23 (0.14, 0.34)	0.26 (0.09, 0.47)	0.31 (0.11, 0.50)	0.32 (0.10, 0.54)	0.32 (0.10, 0.53)	0.35 (0.17, 0.55)	0.35 (0.17, 0.57)	0.36 (0.18, 0.58)	0.34 (0.11, 0.57)
III	0.05 (-0.06, 0.15)	0.04 (-0.15, 0.26)	0.07 (-0.11, 0.25)	0.09 (-0.13, 0.30)	0.07 (-0.12, 0.27)	0.09 (-0.09, 0.28)	0.10 (-0.09, 0.30)	0.11 (-0.11, 0.30)	0.10 (-0.10, 0.28)
aVR	-0.21 (-0.34, -0.14)	-0.24 (-0.38, -0.10)	-0.27 (-0.43, -0.09)	-0.28 (-0.45, -0.10)	-0.28 (-0.44, -0.12)	-0.30 (-0.46, -0.15)	-0.30 (-0.45, -0.15)	-0.31 (-0.45, -0.17)	-0.29 (-0.47, -0.13)
aVL	0.09 (0.01, 0.18)	0.10 (-0.04, 0.22)	0.10 (-0.04, 0.21)	0.09 (-0.06, 0.21)	0.10 (-0.05, 0.22)	0.10 (-0.05, 0.23)	0.09 (-0.05, 0.21)	0.09 (-0.05, 0.23)	0.09 (-0.06, 0.22)
aVF	0.14 (0.05, 0.22)	0.15 (-0.02, 0.35)	0.19 (0.04, 0.35)	0.20 (0.01, 0.37)	0.20 (0.01, 0.38)	0.22 (0.06, 0.39)	0.23 (0.08, 0.42)	0.23 (0.07, 0.43)	0.22 (0.04, 0.41)
V3R	-0.18 (-0.32, -0.10)	-0.26 (-0.41, -0.16)	-0.30 (-0.46, -0.13)	-0.26 (-0.40, -0.08)	-0.24 (-0.37, -0.11)	-0.23 (-0.37, -0.07)	-0.20 (-0.34 ,-0.08)	-0.17 (-0.30, -0.02)	-0.11 (-0.27, 0.08)
V1	-0.18 (-0.43, 0.02)	-0.33 (-0.58, -0.09)	-0.40 (-0.60, -0.17)	-0.35 (-0.56, -0.12)	-0.31 (-0.51, -0.08)	-0.27 (-0.50, 0.06)	-0.18 (-0.45, 0.25)	-0.09 (-0.35, 0.39)	0.02 (-0.35, 0.39)
V2	-0.10 (-0.47, 0.28)	-0.26 (-0.60, 0.17)	-0.36 (-0.70, 0.07)	-0.35 (-0.66, 0.03)	-0.27 (-0.67, 0.26)	-0.08 (-0.51, 0.39)	0.10 (-0.44, 0.65)	0.32 (-0.17, 0.79)	0.48 (0.01, 1.09)
V4	0.30 (0.02, 0.60)	0.27 (-0.12, 0.59)	0.31 (-0.10, 0.68)	0.28 (-0.19, 0.69)	0.34 (-0.11, 0.78)	0.52 (0.08, 0.99)	0.58 (-0.02, 1.11)	0.67 (0.15, 1.19)	0.62 (0.14, 1.26)
V6	0.30 (0.18, 0.45)	0.30 (0.12, 0.53)	0.36 (0.16, 0.61)	0.36 (0.12, 0.59)	0.35 (0.15, 0.63)	0.45 (0.21, 0.74)	0.50 (0.23, 0.85)	0.53 (0.25, 0.94)	0.48 (0.18, 0.88)
V7	0.18 (0.11, 0.27)	0.21 (0.07, 0.34)	0.26 (0.12, 0.42)	0.27 (0.10, 0.44)	0.26 (0.12, 0.43)	0.32 (0.16, 0.52)	0.33 (0.13, 0.52)	0.34 (0.18, 0.56)	0.34 (0.14, 0.58)

Continuous age-dependent normal limits

The figures show continuous normal limits for heart rate and QRS duration, as an illustration of the age-dependent curves used in the PEDMEANS program.

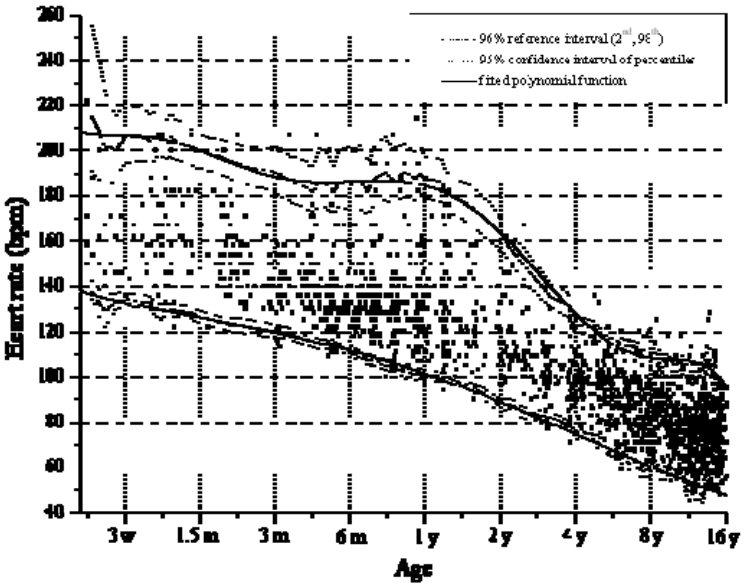

Figure 1. Continuous age-dependent normal limits for heart rate.

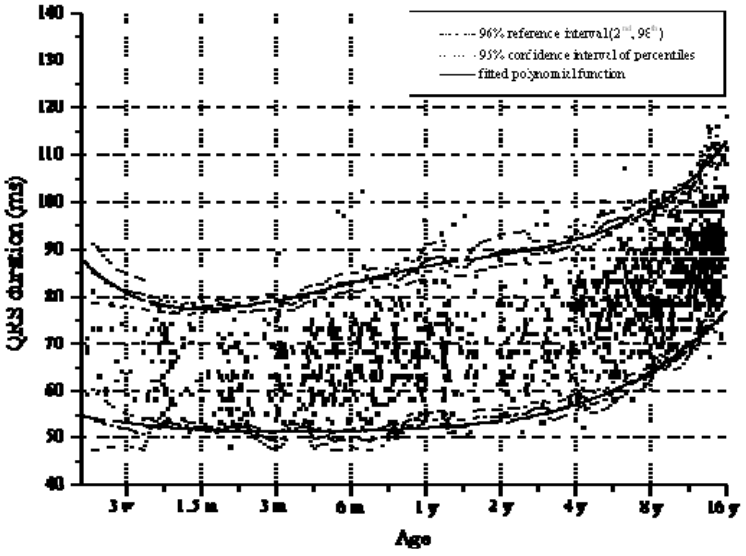

Figure 2: Continuous age-dependent normal limits for QRS duration.