



Welch Allyn

VERITAS with Adult and Pediatric Resting ECG Interpretation

Software V7.3.0, 7.3.1, 7.4.0

Physician's Guide



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1. Preface

This guide describes the criteria that the Baxter **VERITAS** Adult and Pediatric Resting ECG Interpretation algorithm utilizes to analyze and provide interpretive statements for 12-lead ECGs.

Adult criteria are considered for patient ages 16 years and older. Adult descriptions are detailed in the first sections of this guide. Pediatric criteria are considered for patient ages 15 years and younger, including newborns, infants, children and adolescents. Pediatric descriptions are detailed in the last sections of this guide. Several thresholds are age-dependent, and can be found in chapter REFERENCE SUMMARY.

Interpretive statements have two components, the actual interpretive text, and the optional reason statement, which immediately follows in each statement in this Physician's Guide and provides a synopsis of the principle criteria used to reach the specified conclusion. The intention is to provide these reason statements where users find them helpful. They can be omitted on all ECGs via a setup function on the electrocardiograph.

Interpretation of all ECGs proceeds in the sequence of the criteria listing. Ordinarily the last valid statement or conclusion reached within a given section supplants all prior statements.

A condition statement follows each interpretive statement. Conditions and their meanings are listed in order of increasing severity in the table below:

Condition	Meaning
Normal ECG	Normal
Atypical ECG	An unusual ECG pattern, e.g. no QRS detected has been observed but has no specific significance.
Borderline ECG	Criteria have limited specificity or prognostic significance or where only minimal criteria are met.
Abnormal Rhythm ECG	Abnormal Rhythm
CRITICAL TEST RESULT	Criteria for a critical test result are true.
Abnormal ECG	Abnormal
ACUTE MI	Criteria for new or recent myocardial infarction are true or an epicardial injury pattern has been detected
No Further Interpretation Possible	Upon detecting the phenomenon in question, no further useful interpretation of the record is possible.

The statement with the most severe condition provides the conclusion added at the bottom of the interpretive statements when printed. The condition for each statement can be found in the Reference Summary.

Additional statements may be added to the interpretation text. These statements and their meaning are listed in the table below.

Statement	Meaning
DATA QUALITY MAY AFFECT INTERPRETATION	A lead may have been detached during part of the recording. Normally, an ECG is not acquired in this condition, unless the operator specifically overrides the electrocardiograph. Note that in some print formats, not all leads are visible for the full recording duration.
INTERPRETATION BASED ON A DEFAULT AGE OF 40 YEARS	40 years is used for age-dependent criteria. This may happen if the age and date of birth have not been entered on the electrocardiograph when the ECG was recorded.
INTERPRETATION BASED ON A DEFAULT AGE OF 6 MONTHS	6 months is used for age-dependent pediatric criteria. This may happen if an age of "0 years" has been entered on the electrocardiograph when the ECG was recorded. Note that if Date of Birth was entered, the precise age is automatically calculated, and this statement does not occur.

Precautions

The **VERITAS** algorithm generates both a rhythm classification and a contour classification based upon criteria described in this guide. These criteria may sometimes differ from criteria found in ECG textbooks or published literature which are intended to train or educate human ECG readers. Human readers and computer algorithms have different strengths and weaknesses. Human readers are less precise, but better able to evaluate the overall pattern of an ECG as well as including a patient's history and presentation in the evaluation. Computer algorithms are more precise in measuring amplitudes and durations, but less able to evaluate the overall pattern of the ECG and unable to consider a patient's history or presentation. This aspect, coupled with the fact that there are no universally agreed to criteria, means that criteria used for an ECG algorithm will sometimes differ from other published sources.

Statements generated by the **VERITAS** algorithm should always be reviewed by a physician. The ECG algorithm is not intended to replace a physician review of the ECG. Sensitivity and specificity limitations of ECG algorithms, coupled with their inability to incorporate patient history or presentation, underscore the essential need for physician review of any computer generated interpretation statements.

Not all Baxter products are equipped with the pediatric resting ECG interpretation feature.

Refer to the equipment user manual for proper instructions and precautions pertaining to equipment use.

Definitions

Abbreviations used in this guide and in some “reason” statements:

Abbreviation	Description
STJ	ST segment amplitude at QRS offset
STM	ST segment amplitude at ST segment midpoint
STE	ST segment amplitude at ST segment endpoint
T	Peak of the T wave
SSS	S-wave is present in lead I and lead II and lead III

2. Rhythm Statements

Rhythm Statements and Modifiers

VERITAS rhythm statements describe the predominant rhythm in the 10 seconds of analyzed data. A modifier, listed after the rhythm statements, may also be added to more accurately describe the type of rhythm. The main rhythm statements and their criteria follow.

Rhythm Statements

- Sinus Rhythm
- Ectopic Atrial Rhythm
- Junctional Rhythm
- Supraventricular Rhythm

- Idioventricular Rhythm

- Uncertain Regular Rhythm
- Uncertain Irregular Rhythm

- Atrial Fibrillation
- Atrial Flutter/Tachycardia

- Electronic Atrial Pacemaker
- Electronic Ventricular Pacemaker

Qualifications of the above rhythm statements based on rate are also generated. For example: “Sinus” may be Sinus Bradycardia, Sinus Rhythm, or Sinus Tachycardia. These rate qualifications are made for Sinus, Ectopic Atrial, Junctional and Supraventricular rhythm statements. Criteria for limits of Bradycardia and Tachycardia based on age are included in the Reference Summary.

Rhythm Statement Criteria

The rationale behind generation of the rhythm statements is described in the following sections. It is important to note that these descriptions are intended to provide a general overview of the **VERITAS** algorithm logic in a compact reference form. As such, some details and dependencies have been intentionally omitted to improve readability and understanding.

Electronic Atrial or Ventricular Pacemaker

In interpreting resting ECGs where a pacemaker is present, it is important to note that the **VERITAS** program does not attempt to assess pacemaker performance criteria such as failure to capture or failure to sense. The 10-second ECG is not adequate in duration for an algorithm to make this determination. All pacemaker generated statements are based upon pacing impulses that have been captured and hence resulted in stimulation of atrial or ventricular activity.

There are two independent tests for pacemaker detection: hardware-driven detection (hard pace detection) and software-driven detection (soft pace detection). Hard pace detection is based upon triggering hardware flags and the repeated presence of these flags in a minimum number of beats. These hardware flags are based upon detection of “spikes” in the high resolution front-end data stream (10,000 – 40,000 samples/second depending upon ECG front-end) preceding either atrial activity, ventricular activity, or both. If the hard pace criteria are met,

then the appropriate pacemaker statement is set and the subsequent soft pace detection step is skipped.

Soft pace detection utilizes the acquisition data stream (1,000 samples/second) and inspects high frequency, “spike” activity, before atrial and ventricular complexes. This secondary test is used to detect impulses that did not pass the hard pace detection due to low amplitude and/or temporally wide pulses.

The distinction between atrial and ventricular pacing is made on the basis of the latency between the spike and the QRS complex.

The combined results of applying these two tests are presented in the *VERITAS Resting ECG Interpretation Evaluation* section.

If both electronically paced and intrinsic QRS complexes are found, the phrase “-- contour analysis based on intrinsic rhythm” is added to the statement. Most statements based on contour analysis are suppressed for paced complexes, with the exception of the most severe level of ST-elevation statements. Although this can lead to false positive “Acute MI” statements, this was deemed acceptable given the relatively low percentage of artificially paced ECGs in most hospital populations.

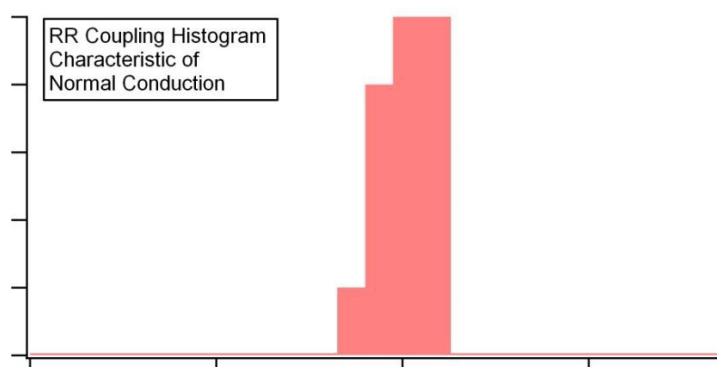
Atrial Flutter/Tachycardia

The Atrial Flutter/Tachycardia statement is generated if flutter waves (P-P) are detected with a rate above 200 and less than 350 beats per minute. Additionally, in the presence of a ventricular rate above 140 beats per minute, a statement of “Possible Atrial Flutter” will be generated.

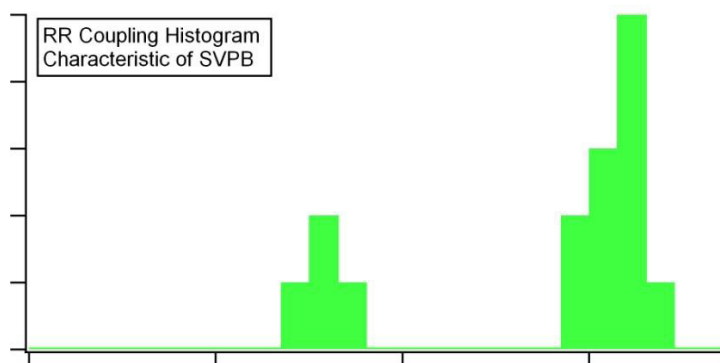
Note that the P-wave axis and PR interval are not defined in the presence of atrial flutter and hence will not be determined by VERITAS.

Atrial Fibrillation

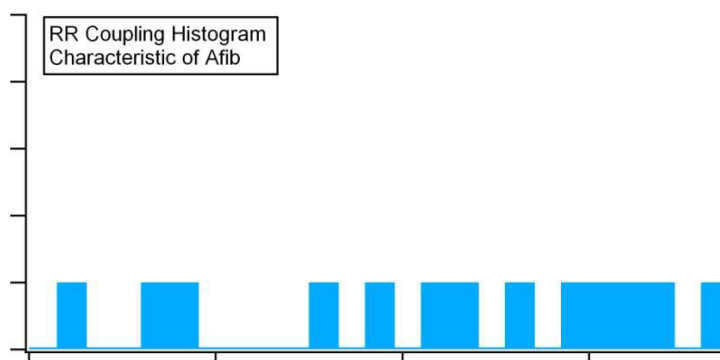
The Atrial Fibrillation statement is triggered based on the presence of low amplitude or undetected P waves in combination with a disorganized rhythm. A disorganized rhythm is characterized by the lack of “clustering” of RR intervals, while highly clustered RR intervals are indicative of an organized rhythm. The clustering criteria are utilized to distinguish premature atrial contractions, from atrial fibrillation as illustrated in the following RR histograms.



Sample RR histogram of normal conduction. Note single cluster of RR intervals characteristic of normal conduction at steady sinus rate.



Sample RR histogram in presence of SVPBs. Note two clusters of RR intervals. The larger cluster would be associated with the normal conduction, the smaller, shorter RR with SVPBs.



Sample RR interval histogram for atrial fibrillation. Note lack of clustering.

Note that the P-wave axis and PR interval are not defined in the presence of atrial fibrillation and hence will not be determined by VERITAS.

Sinus Rhythm

Sinus Rhythm is called in the presence of a normal P-wave axis, between -45 and 120 degrees. For a P-wave axis outside of this range, Ectopic Atrial or Junctional Rhythm is considered.

Junctional Rhythm

The Junctional Rhythm statement is generated in the presence of a superior P-wave axis between -60 and 240 degrees coupled with a short PR interval (less than 140 milliseconds).

Ectopic Atrial

The Ectopic Atrial Rhythm statement is generated in instances when the P-wave axis is outside of the criteria for Sinus Rhythm, but the PR interval is not shortened.

Supraventricular Rhythm

In instances when the QRS is narrow and the rhythm is organized, but no P-wave is detected, a statement of Supraventricular Rhythm is generated. The narrow QRS suggests conduction through the AV node, but the lack of P-wave detection leaves uncertainty as to whether the rhythm is Sinus or Ectopic Atrial in origin.

Note that the P-wave axis and PR interval are not defined when no P-wave is detected by **VERITAS**. Hence, these values will not be determined.

Idioventricular Rhythm

The Idioventricular Rhythm statement is generated with a slow (less than 45 beats per minute), wide QRS rhythm.

Uncertain Regular/Irregular Rhythm

The Uncertain Regular Rhythm statement is generated when a wide QRS rhythm with no apparent P-wave and regular RR interval is present. The Uncertain Irregular Rhythm statement is generated when a wide QRS rhythm with no apparent P-wave and irregular RR interval is present.

The previous rhythm statements can be qualified with the following modifiers.

Modifiers

- ...with (marked) sinus arrhythmia
- ...with first degree AV block ("prolonged PR interval for age" for pediatric records)
- ...with short PR interval
- ...with second degree AV block, Mobitz Type (I, II)
- ...with high grade AV block
- ...with (occasional/frequent) ventricular premature complexes
- ...with (occasional/frequent) ectopic premature complexes
- ...with (occasional/frequent) atrial premature complexes
- ...with (occasional/frequent) supraventricular premature complexes
- ...in a pattern of bigeminy
- ...with marked rhythm irregularity, possible non-conducted PAC, SA block, AV block, or sinus pause
- ...possible atrial flutter (regular rate near 150)
- ...contour analysis based on intrinsic rhythm (pacemaker rhythm alternated with intrinsic rhythm)
- ...intermittent ventricular preexcitation/WPW

Modifiers Used with Atrial Fibrillation or Flutter

- ...with (rapid/slow) ventricular response
- ...with aberrant conduction or ventricular premature complexes

3. Median Beat Formation and Measurements

The following summary provides a high-level review of how the Baxter **VERITAS** algorithm performs automatic ECG measurements. The general flow of how the Baxter algorithm functions is illustrated below.

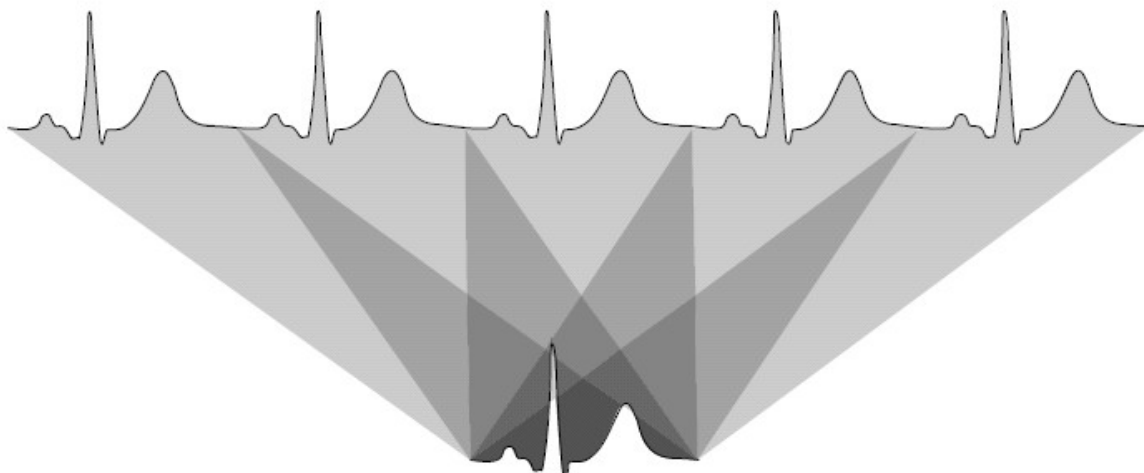


Simultaneous Acquisition

Following 12-lead or 15-lead simultaneous ECG acquisition using front end sampling rates of 10,000 or 40,000 kHz, ECG analysis is performed at 1000 samples/second/channel. Electrocardiographs using a **WAM** or **AM12** acquisition module feature 40,000 kHz sampling, all others feature 10,000 kHz sampling. The high resolution sampling rate is used to detect pacemaker pulses on the surface ECG. All other analysis is performed at the 1000 samples/second data resolution.

Median Beat Formation

The Baxter algorithm forms median beats from all 12 leads of the ECG. Median beats are utilized to minimize the impact of noise present in any given single beat. Multiple global measurements can be determined utilizing the median beats including the PR, QRS, and QT duration. Median beat formation involves the identification of a “primary” beat type within a sequence of beats. This categorization identifies beats which are to be included in the median or representative beat formation. Beats which are not considered part of the “primary” class are not included in the formation of the median. In applying these criteria, beats such as occasional premature ventricular complexes are excluded from the median beat formation. Following selection of beats, the beats are aligned and combined to form the median beat. This concept is schematically illustrated in the figure below.



MEDIAN BEAT FORMATION AND MEASUREMENTS

Global Measurements

With the median beats constructed, a series of “global” measurements can be obtained. These measurements are global in the sense that they are not lead specific, but rather span the 12-lead simultaneous data.

In the case of the PR, QRS and QT duration, the **VERITAS** algorithm determines onsets and offsets by reference to a composite measure of electrical activity reflecting the total activity across all leads. Specific comments for individual measurements follow.

QT

The Baxter algorithm determines QT from the interval between the earliest ventricular depolarization activity and the latest “end-of-T”, considering all leads. This determination utilizes median beats, which reduce the effects of noise. A composite measure of electrical activity, reflecting the total activity across all leads, is formed from these median beats. This composite measure is then utilized to infer the moment of earliest ventricular depolarization and the latest “end-of-T”. This “global QT” is naturally longer (statistically) than the QT measured in a single lead, due to the impact of isoelectric onsets/offsets in a single lead measurement. Moreover, in the presence of QT interval increases within a single individual’s ECG, concomitant axis shifts of the T wave may cause the full extent of the QT increase to be more accurately recorded by the global QT measure.

QRS

The **VERITAS** algorithm determines QRS duration as the earliest QRS onset (as manifested in any of the 12-lead medians) to the latest QRS offset (considering all 12-lead medians). Comments regarding the “global QT” above similarly apply for the “globalQRS”.

PR

Using the 12-lead median beats, the Baxter algorithm determines the PR interval using the global onset for the P wave to the global onset of the QRS.

RR

The Baxter algorithm utilizes an average RR interval over 10 second period.

Individual Lead Measurements

Amplitudes and lead specific intervals, unlike global interval duration measurements, are performed on an individual lead basis. These measurements are determined using individual lead median beats and criteria are applied as described in the following sections.

For individual lead duration measurements on the first and last wave of a QRS complex, the global QRS onset and offset are used by the interpretation program to determine the beginning or end of the wave. This may result, for instance, in a slightly longer Q-duration used by the program compared to paper measurement on the single lead, if the first part of the activation in the particular lead is isoelectric.

ⁱ It should be noted that although the term “median” is used, the median beat is not a statistical median in the formal mathematical sense. It is a combination of both averaging and median techniques applied to the ECG signal.

4. Adult Criteria

Arm Lead Reversal and Dextrocardia

Criteria

IF	THEN
No Q in lead I and R amplitude < 150µV in lead I or Q amplitude > 0 in lead I and P axis > 90 and PR duration ≥ 110 ms and QRS axis > 90	PRINT "Arm leads reversed" REASON: <i>Inverted P & QRS in lead I</i>
If above criteria are met and R amplitude < 500 µV in lead V6 and Maximum S amplitude > Maximum R amplitude in lead V6 and P amplitude < 20 µV in lead V6 and P' amplitude < -20 µV in lead V6	PRINT "Dextrocardia" REASON: <i>Inverted P & QRS in V6</i>

Rationale

Simultaneously negative P and QRS contours in lead 'I' are unlikely in a properly recorded ECG. If, in addition, the QRS has a Qr (or rSr') configuration, the most probable explanation is that the arm leads are reversed or dextrocardia is present. If lead V6 has a typical upright configuration, arm lead reversal is more likely; otherwise, dextrocardia is the remaining plausible explanation.

Although the reason statement for both lead reversal and dextrocardia mentions only the inverted P & QRS, the requirement of Qr/rSr' morphology is important to distinguish these cases from pulmonary disease and right ventricular hypertrophy patterns, where rS configurations are the norm. (Further separation from the latter is ensured by the requirement of an inverted P.)

Ventricular Preexcitation

SKIP TEST IF

The test for coupled P wave to QRS is negative

or PR duration > 170 ms

or QRS duration < 100 ms

or Heart rate > 120 BPM

or QRS duration > 200 ms

or PR duration > 100 ms and QRS duration > 160 ms

Criteria

IF

PR duration < 140 ms

and Delta wave is present in 2 leads

or

Delta wave is present in 2 leads

and R amplitude > S amplitude in V1

or

QRS area ratio ≥ 0.6 in 2 leads of I/V5/V6 and R

duration > 30 ms in V2

or Delta wave is present in 2 leads and

PR duration is < 140 ms

and R amplitude $\leq$ S amplitude in V1

THEN

PRINT "Ventricular preexcitation/WPW"

Atrial Enlargement

Criteria

IF	THEN
Heart rate < 120 and P amplitude > 250 μ V in any 1 of leads II/III/aVF/V1/V2	PRINT "Possible right atrial enlargement" REASON: <i>0.25 mV P wave</i>
Heart rate < 120 and P amplitude > 300 μ V in any 1 of leads II/III/aVF/V1/V2	PRINT "Right atrial enlargement" REASON: <i>0.3 mV P wave</i>
P' amplitude < -100 μ V in V1 or V2 and negative P wave area $\geq$ 400 μ V/ms in the same lead	PRINT "Possible left atrial enlargement" REASON: <i>-0.1 mV P wave in V1/V2</i>
P' amplitude < -150 μ V in V1 or V2 and negative P wave area $\geq$ 600 μ V/ms in the same lead	PRINT "Left atrial enlargement" REASON: <i>-0.15 mV P wave in V1/V2</i>

Rationale

The criteria are the customary ones. For those records meeting only minimal criteria, the qualifier "possible" is used to convey this information. Right atrial enlargement is not "read" for rates of 120 or above, because it is unclear whether increased P amplitude at elevated rates should be attributed to enlargement.

Axis Deviation

Criteria

IF	THEN
QRS axis < -20	PRINT "Borderline Left axis deviation" REASON: <i>QRS axis < -20</i>
QRS axis < -30	PRINT "Marked Left axis deviation" REASON: <i>QRS axis < -30</i>
QRS axis > 90	PRINT "Borderline Right axis deviation" REASON: <i>QRS axis > 90</i>
QRS axis > 100	PRINT "Marked Right axis deviation" REASON: <i>QRS axis > 100</i>
The total net QRS amplitude in leads I, II, and III is < 33% of the total QRS deflection in leads I, II, and III.	PRINT "Indeterminate axis"

Rationale

The criteria are more or less conventional. (Axis deviation statements are omitted when subsequently identified diagnostic categories may be regarded as the probable cause of the axis deviation.)

Whenever the net amplitude is a small fraction of the total QRS deflection in each lead, the measurement of axis is lacking in meaning. The term "indeterminate axis" is used to convey this information.

Low Voltage

SKIP TEST IF

QRS duration $\geq$ 120 ms

Criteria

IF	THEN
Total QRS deflection < 500 μ V in all limb leads	PRINT "Low QRS voltage in extremity leads" REASON: <i>QRS deflection < 0.5 mV in limb leads</i>
Total QRS deflection < 1000 μ V in all V leads	PRINT "Low QRS voltage in precordial leads" REASON: <i>QRS deflection < 1.0 mV in chest leads</i>
If both of the above are true	PRINT "Low QRS voltage" REASON: <i>QRS deflection < 0.5/1.0 mV in limb/chest leads</i>

S1-S2-S3 Pattern

Criteria

IF	THEN
S amplitude > 300 μ V in I and S amplitude > 400 μ V in II and S amplitude > 700 μ V in III or S amplitude > R amplitude in leads I, II & III and S amplitude > 200 μ V in leads I, II & III and the test for R' is negative in any of these leads and age > 15	PRINT "S1-S2-S3 pattern, consistent with pulmonary disease, RVH, or normal variant"

Pulmonary Disease

SKIP TEST IF

QRS duration ≥ 120 ms

Criteria

The test for pulmonary disease is based on counting how many of its typical characteristics are present. One point is awarded for each of

- Right atrial enlargement
- QRS axis < -30
- QRS axis > 90
- QRS axis is indeterminate
- S1-S2-S3 pattern
- Low voltage in limb leads
- Low voltage in chest leads

Three points are awarded if QRS net amplitude is negative in lead V5 and the R (and R') amplitude in V6 $< 500 \mu\text{V}$.

IF

Cumulative points > 3

THEN

PRINT "Pattern consistent with pulmonary disease"

Rationale

There is room to doubt whether sufficient ECG criteria exist to diagnose pulmonary disease. However, if at least 4 (from a list of 8 distinct) features common to pulmonary disease are present, then the comment "consistent with" seems prudent.

5. Adult Conduction Abnormalities

Right Bundle Conduction

Criteria

IF	THEN
R amplitude > 100 μV in V1 & V2 and R duration > 20 ms in V1 and V2 and no S in V1 or V2 or R' amplitude > 100 μV in V1 & V2 and R' duration > 20 ms in V1 & V2 and no S' in V1 or V2	PRINT "Possible right ventricular conduction delay" REASON: RSR (QR) in V1/V2
Either of the above is true and QRS duration > 90 ms and QRS duration < 120 ms and S duration $\geq$ 40 ms in any 2 leads of I/aVL/V4/V5/V6	PRINT "Incomplete right bundle branch block" REASON: 90+ ms QRS duration, terminal R in V1/V2, 40+ ms S in I/aVL/V4/V5/V6
QRS duration $\geq$ 120 ms and S duration $\geq$ 40 ms in any 2 leads of I/aVL/V4/V5/V6 or R duration > 60 ms and R amplitude > 500 μV in V1 and R duration < 100 ms in any 4 leads of I/aVL/V4/V5/V6 and QRS area > 0 in V1 and V1 does not terminate in S or S' or QRS duration > 105 ms and S duration $\geq$ 60 ms in any 3 leads of I/aVL/V4/V5/V6 and R duration > 60 ms in V1 and QRS area > 0 in V1	PRINT "Right bundle branch block" REASON: 120+ ms QRS duration, upright V1, 40+ ms S in I/aVL/V4/V5/V6
The test for right bundle branch block is positive and R amplitude > 1500 μV in V1 and QRS axis > 110	PRINT "Right bundle branch block and possible Right Ventricular Hypertrophy" REASON: RBBB, 1.5 mV R in V1, RAD

Rationale

Right bundle branch conduction abnormalities exhibit anterior and rightward directed terminal forces. The rightward force should be noticeably prolonged. Thus, in addition to QRS conducting time criteria, tests are included for a widened terminal R wave in V1 and widened terminal S waves in at least two of the lateral leads. Conventional criteria require QRS widths in excess of 0.12 seconds for bundle branch block. However, very wide lateral S waves, a wide R in an upright V1, and QRS duration > 105 ms will also be read as right bundle branch block by most interpreters. This is the basis of the second portion of the complete right bundle branch block test. Specific criteria for right bundle branch block + right ventricular hypertrophy are also included.

Left Bundle Conduction

Criteria

IF	THEN
QRS duration > 105 ms and QRS net amplitude < 0 in V1 & V2 and S duration ≥ 80 ms in V1 & V2 and no Q is present in 2 leads of I/V5/V6 and R duration ≥ 60 ms in 2 leads of I/aVL/V5/V6	PRINT "Moderate intraventricular conduction delay" REASON: <i>105+ ms QRS duration, 80+ ms Q/S in V1/V2, no Q and 60+ ms R in I/aVL/V5/V6</i> Note: This pattern is sometimes described as "Incomplete left bundle branch block"
QRS axis ≤ -45 and R amplitude > Q amplitude in I & aVL and a Q is present in I and S or S' amplitude > R amplitude in II	PRINT "Left anterior fascicular block" REASON: <i>QRS axis ≤ -45, QR in I, RS in II</i>
The test for S1-S2-S3 is negative, and the test for Pulmonary Disease is negative and QRS axis ≥ 110 and R amplitude > Q amplitude in III & aVF and a Q is present in III & aVF	PRINT "Left posterior fascicular block" REASON: <i>QRS axis > 109, inferior Q</i>
QRS net amplitude < 0 in V1 & V2 and S duration ≥ 80 ms in V1 & V2 and Q amplitude < 50 μV in 2 leads of I/V5/V6 and R duration ≥ 60 ms in 2 leads of I/aVL/V5/V6 and QRS area ratio > 0.25 in I or V6 and R duration ≥ 100 ms in 1 lead of I/aVL/V6 and QRS duration ≥ 160 ms or QRS duration ≥ 140 ms and the average R duration > 85 ms in I/aVL/V6 or QRS duration ≥ 120 ms and the average R duration > 85 ms in I/aVL/V6 and QRS area ratio > 0.4 in 2 leads of I/aVL/V6	PRINT "Left bundle branch block" REASON: <i>120+ ms QRS duration, 80+ ms Q/S in V1/V2, 85+ ms R in I/aVL/V6</i>

Rationale

The meaning of incomplete left bundle branch block beyond describing an ECG pattern is unknown. For this reason the wording of the statement is generic, the criteria are narrowly defined, and whenever a specific label such as left anterior fascicular block is available, the term incomplete left bundle branch block is suppressed.

The test for left bundle branch block introduces a measurement called the “QRS area ratio,” which is defined as the ratio of the QRS area (algebraic) to the area of a rectangle defined by QRS onset and offset and the peak positive amplitude. The area ratio is large whenever the QRS is upright and has a wide or notched R wave peak. The thresholds used in the above left bundle branch block tests are empirically determined to correlate with typical left bundle branch block patterns. The area ratio is used in lieu of R duration in order to better discriminate between true left bundle branch block and a monophasic (upright) QRS with nonspecific terminal slurring of the R wave leading to increased QRS duration.

Strict criteria for fascicular blocks are used. This should be noted by readers who use simple axis deviation tests.

Non-Specific Conduction Abnormality

Criteria

IF	THEN
The test for Right Bundle Branch Block is negative and The test for Incomplete Right Bundle Branch Block is negative and The test for Left Bundle Branch Block is negative and The test for Incomplete Left Bundle Branch Block is negative and The test for left anterior fascicular block is negative and The test for left posterior fascicular block is negative and The test for RSR Pattern is negative and QRS duration > 110 ms	PRINT "Moderate intraventricular conduction delay" REASON: <i>110+ ms QRS duration</i>
The test for Right Bundle Branch Block is negative and The test for Left Bundle Branch Block is negative and QRS duration > 130 ms	PRINT "Intraventricular conduction delay" REASON: <i>130+ ms QRS duration</i>

Rationale

Moderate intraventricular conduction delay is used to connote moderate QRS widening which does not fit any previously defined pattern. Intraventricular conduction delay is used with marked QRS widening. The term "block" is avoided, since the reason for the slow conduction is not clear.

6. Adult Hypertrophy

Right Ventricular Hypertrophy

SKIP TEST IF

The test for either arm lead reversal, ventricular rhythm, electronic ventricular pacemaker, ventricular preexcitation, right bundle branch block or left bundle branch block is positive

or age < 16

or S amplitude < 250 μ V in I

or S amplitude > 1000 μ V in V1

or QRS axis < 60

or QRS duration > 140 ms and net QRS amplitude < 0 in V1

or Q amplitude > S amplitude and R exists in I

Criteria

The test for right ventricular hypertrophy is based on counting how many of (or in what degree) its common characteristics are present.

One point is awarded for each of:

- R/R' amplitude > 500 μ V in V1
- Net QRS amplitude > 0 in V1
- Net QRS amplitude > 500 μ V in V1
- Net QRS amplitude < 0 and S amplitude > 500 μ V in V5 or V6
- QRS axis $\geq$ 90
- QRS axis $\geq$ 100
- QRS axis $\geq$ 110
- Possible right atrial enlargement has been called
- S1, S2, S3 is present
- Age > 30
- If Indeterminate Axis is true, no points are given for QRS axis

IF	THEN
Cumulative points > 3	PRINT "Possible right ventricular hypertrophy" REASON: <i>Some/all of: prominent R in V1, late transition, RAD, RAE, SSS</i>
Cumulative points > 5	PRINT "Right ventricular hypertrophy" REASON: <i>Some/all of: prominent R in V1, late transition, RAD, RAE, SSS</i>
The test for possible right ventricular hypertrophy is positive and STJ > STM > STE or one of (STM, STE, and T) < -100 μ V in V1, V2, and V3 and QRS duration < 120 ms	PRINT "Right ventricular hypertrophy and ST-T change" REASON: <i>Some/all of: prominent R in V1, late transition, RAD, RAE, SSS, right precordial ST depression</i>

NOTE: STJ = ST segment amplitude at QRS offset; STM = ST segment amplitude at ST segment midpoint; STE = ST segment amplitude at ST segment endpoint; T = peak of the T wave.

Left Ventricular Hypertrophy

Criteria

Tests for left ventricular hypertrophy include various voltage criteria, QRS duration, repolarization abnormalities (strain), and left atrial enlargement (as a correlated factor). To arrive at composite voltage criteria, the common standard criteria are scored by degree of excess over the appropriate threshold. These thresholds depend on the age of the patient, as well as the lead or combination of leads.

SKIP TEST IF

The test for either arm lead reversal, ventricular rhythm, electronic ventricular pacemaker, ventricular preexcitation, or left bundle branch block is positive

or QRS duration > 140 ms

and net QRS amplitude < 0 in V1

Thresholds

AGE	S(V1)	R(V5)	R(Max of V5 or V6) + S(V1)
<20	--	--	--
20-29	3.0 mV	3.0 mV	4.5 mV
30-39	2.4 mV	2.6 mV	4.0 mV
40+	2.4 mV	2.6 mV	3.5 mV

A threshold of 1.1 mV for R (aVL) is used independent of age or sex.

Voltage Criteria

IF	THEN SCORE
R/R'(aVL) > 1.1 mV	2 points + 1 point/0.1 mV excess
S/S'(V1) > threshold	2 points + 1 point/0.2 mV excess
R/R'(V5) > threshold	2 points + 1 point/0.2 mV excess
R/R' (V5/V6)+S/S_(V1) > threshold	2 points + 1 point/0.3 mV excess

The measure of QRS conduction time in the context of left ventricular hypertrophy is from QRS onset to the peak negative second derivative after the R peak in V5. Ordinarily, the latter point corresponds to the S nadir:

IF	THEN
Cumulative points > 0	Left ventricular hypertrophy is possible
Cumulative points > 2	Moderate voltage criteria for left ventricular hypertrophy exists
Cumulative points > 4	Voltage criteria for left ventricular hypertrophy are present
Peak 2nd derivative - QRS onset > 68 ms in V5	The conduction time threshold is met
The test for Atrial Fibrillation is negative and (STE < STJ) and (STE < -50 μ V) and (R amplitude > 1100 μ V) in at least 1 lead of I, aVL, V4, V5 and V6	Left ventricular hypertrophy exists with repolarization abnormalities
or T amplitude (V1) - T amplitude (V6) > 200 μ V	
Cumulative points are > 0 and the conduction time threshold is exceeded	Non-voltage criteria for left ventricular hypertrophy are present.
or the criteria for possible left atrial enlargement are met	
or left ventricular hypertrophy with repolarization abnormalities exists	
Cumulative points are > 0 and voltage criteria exist for left ventricular hypertrophy	PRINT "Minimal voltage criteria for left ventricular hypertrophy, consider normal variant" REASON: <i>Meets criteria in one of: R(aVL), S(V1), R(V5), R(V5/V6)+S(V1)</i>
Cumulative points are > 2 and voltage criteria exist for left ventricular hypertrophy	PRINT "Moderate voltage criteria for left ventricular hypertrophy, consider normal variant" REASON: <i>Meets criteria in one of: R(aVL), S(V1), R(V5), R(V5/V6)+S(V1)</i>

Left Ventricular Hypertrophy Criteria (Continued)

IF	THEN
Cumulative points are > 4 and voltage criteria exist for left ventricular hypertrophy	PRINT "Voltage criteria for left ventricular hypertrophy" REASON: <i>Meets criteria in one of: R(aVL), S(V1), R(V5), R(V5/V6)+S(V1)</i>
Non-voltage criteria are met and the test for repolarization abnormalities is negative	PRINT "Possible left ventricular hypertrophy" REASON: <i>Voltage criteria plus LAE or QRS widening</i>
Non-voltage criteria are met and repolarization abnormalities exist	PRINT "Left ventricular hypertrophy and ST-T change" REASON: <i>Voltage criteria plus ST/T abnormality</i>
Cumulative points are > 2 or Non-voltage criteria are met	A flag for Left Ventricular Hypertrophy is set which is used in conjunction with other criteria

Rationale

ECG criteria for left ventricular hypertrophy are imperfect. The sensitivities of various favorite voltage criteria are not better than 30-40%. Specificities greater than 90% may initially seem sufficient, but application to a general population would evidently generate more false than true positives. The philosophy in the above criteria has been to combine several voltage criteria in order to increase the net sensitivity. In order to minimize the impact of an unavoidable decrease of specificity, records minimally exceeding only one criterion and exhibit no non-voltage criteria are identified as possible normal variants. In all cases, records meeting only voltage criteria are identified as such.

Non-voltage tests for left ventricular hypertrophy include the presence of left atrial enlargement, QRS widening, and repolarization changes. Whenever any of these are present in combination with at least one voltage criterion, a stronger statement is made. A new measure of QRS widening is used in place of intrinsicoid deflection time and/or the total QRS width. Instead, an attempt is made to measure the duration of leftward forces in lead V5. The motivation is to be more sensitive than intrinsicoid timing, while avoiding spurious increases in total QRS duration.

Repolarization changes, for the purpose of identifying non-voltage left ventricular hypertrophy criteria, include depressed, downsloping ST segments in any of the lateral leads, or a T amplitude in V1 greater than that in V6.

7. Adult Myocardial Infarct

Myocardial Infarct Discussion

Computer criteria for myocardial infarct depart from standard textbook criteria in greater degree than most electrocardiographers would probably expect. The reason is that conventionally accepted criteria describe stereotypical infarction. When these criteria are applied, they have a high specificity, but a very low sensitivity. For example, a recent review of inferior infarct criteria reported a sensitivity of only 4% using New York Heart Association criteria. In order to achieve more useful results, computer programs must incorporate some of the same unpublished “unconventional” criteria used by experienced ECG interpreters.

Conventional criteria focus on Q wave duration as the primary test for the presence of infarction, and the computer tests that follow naturally retain this focus. The single most important additional criterion, seldom mentioned in reviews in infarction criteria, is a test for repolarization abnormalities characteristic of acute or recent infarction. For example, elevated ST segments and negative T waves are strong indicators of infarction in the presence of otherwise non-diagnostic Q waves. Taking into account these repolarization abnormalities greatly increases both sensitivity and specificity for new or recent infarcts. For old infarcts, the problem is more complex. Gains can be made by considering Q and R wave amplitudes and QRS duration. These factors are quantitatively added by converting to “Q duration equivalents.” Thus for every 30 μV of Q amplitude, 1 ms is added to the actual Q duration to obtain an “equivalent” duration. Likewise, for each 120 μV of R amplitude, 1 ms is subtracted, and for every 4 ms of QRS duration beyond 100 ms, 1 ms is added (up to a maximum correction of 5 ms), or subtracted for durations less than 100 ms. This last factor attempts to exploit the frequent increase in QRS duration concomitant with infarction, whether due to left ventricular hypertrophy, peri-infarction block or other types. To further reduce the impact of a wide, but very small Qs, the equivalent duration is reduced by 1 ms for every μV that the Q amplitude is short of 100 μV .

Age and sex affect the a priori probability of infarction. These factors are also incorporated by modifying the equivalent Q duration. For males, 1 ms is subtracted from the equivalent Q duration for every two years under the age of 40, up to a maximum correction of 10 ms. Likewise, for females, 1 ms is subtracted for every two years under 50, again up to a maximum of 10 ms.

It should be noted that the above adjustments to the equivalent Q duration are not very large, and should not be expected to cause unreasonable departures from conventional interpretation. Mostly, they can expect to affect the certainty attached to a given interpretation.

With some exception, infarct diagnostic statements are given qualifiers intended to reflect the certainty of the particular interpretation. These qualifiers are:

Possible	Typical equivalent Q duration 30-34 ms
Probable	Typical equivalent Q duration 35-39 ms
(Unqualified)	Typical equivalent Q duration 40+ ms

The presence of repolarization abnormalities characteristic of the infarct can cause the qualifier to be omitted, that is, upgrade to strongest statement.

8. Anterior Infarct

Define: Alternate T amplitude =

1. If the test for T' is negative, T - larger of STE or T end
2. If the test for T' is positive, lesser of T & T' - larger of STE or T end

SKIP TEST IF

The test for either arm lead reversal, ventricular rhythm, electronic ventricular pacemaker, ventricular preexcitation or left bundle branch block is positive

or

QRS duration > 140 ms and net QRS amplitude < 0 in V1

Criteria

IF	THEN
STM and STE amplitude > 200 μ V in V3 and V4 and Alternate T amplitude $\geq$ 0 in V3 and V4	Conditions for a new anterior infarct are present
STM and STE amplitude > 50 μ V in V3 or V4 and Alternate T amplitude < 0 in V3 or V4	Conditions for a recent anterior infarct are present
Criteria for a new or recent anterior infarct are not met and STM amplitude < 30 μ V in V3 and V4 and Alternate T amplitude $\geq$ 0 in V3 and V4	Conditions for an old anterior infarct are present
Criteria for a new, recent or old anterior infarct are not met	The age description is "of indeterminate age"
Equivalent Q duration $\geq$ 30 ms in V2 or V4	Test 1 for anterior infarct is positive
Equivalent Q duration $\geq$ 30 ms in V3 or V5	Test 2 for anterior infarct is positive
Equivalent Q duration $\geq$ 30 ms in V3 and Test 1 for anterior infarct is positive or Equivalent Q duration $\geq$ 30 ms in V4 and Test 2 for anterior infarct is positive or R amplitude < 200 μ V in V4	PRINT "Possible anterior infarct" REASON: 30 ms Q wave in V3/V4 or R < 0.2 mV in V4
Equivalent Q duration $\geq$ 35 ms in V3 and Test 1 for anterior infarct is positive and the left ventricular hypertrophy flag is not set or Equivalent Q duration $\geq$ 35 ms in V4 and TEST 2 for anterior infarct is positive	PRINT "Probable anterior infarct" REASON: 35 ms Q wave in V3/V4

Anterior Infarct Criteria (Continued)

IF	THEN
Equivalent Q duration ≥ 40 ms in V3 and Test 1 for anterior infarct is positive and the left ventricular hypertrophy flag is not set and the test for low voltage in the chest leads is negative and the test for non-specific intraventricular conduction block is negative or Equivalent Q duration ≥ 40 ms in V4 and Test 2 for anterior infarct is positive or If the test for "Possible anterior infarct" is positive and either recent or new criteria have been met	PRINT "Anterior infarct" REASON: <i>40+ ms Q wave and/or ST/T is abnormality in V3/V4</i>

IF	THEN APPEND
Anterior infarct is new	Possibly acute
Anterior infarct is recent	Probably recent
The age of the anterior infarct is undetermined	Of indeterminate age
Anterior infarct is old	Probably old

Septal Infarct

SKIP TEST IF

The test for either arm lead reversal, ventricular rhythm, electronic ventricular pacemaker, ventricular preexcitation or left bundle branch block is positive

or

the test for anterior infarct is positive

and Q amplitude > 0 in V1

or

QRS duration > 140 ms and net QRS amplitude < 0 in V1

Criteria

IF	THEN
STM and STE amplitude > 200 μ V in V2 and alternate T amplitude ≥ 0 in V2	"New" septal infarct is present
STM and STE amplitude > 50 μ V in V2 and alternate T amplitude < 0 in V2	"Recent" septal infarct is present
Septal infarct is not new or recent and STM amplitude < 50 μ V in V2 and alternate T amplitude ≥ 0 in V2	Septal infarct is "old"
The criteria for a septal infarct have been met and it is neither new, recent, or old	Qualifier "Of indeterminate age" will be used
Equivalent Q duration ≥ 30 ms in V2 or the test for Right Bundle Branch Block is positive and Equivalent Q duration > 20 ms in V2	PRINT "Possible septal infarct" REASON: <i>30 ms Q wave in V1/V2</i>
Equivalent Q duration ≥ 35 ms in V2 and left ventricular hypertrophy flag is not set	PRINT "Probable septal infarct" REASON: <i>35 ms Q wave in V1/V2</i>
Equivalent Q duration ≥ 40 ms in V2 and the left ventricular hypertrophy flag is not set	PRINT "Septal infarct" REASON: <i>40+ ms Q wave in V1/V2</i>
IF	THEN APPEND
Septal infarct is new	Possibly acute
Septal infarct is new	Probably recent
The age of the septal infarct is undetermined	Of indeterminate age
Septal infarct is old	Probably old

Anteroseptal Infarct

SKIP TEST IF

Positive criteria for a Lateral Infarct exists

Criteria

IF	THEN
Both an anterior infarct and a septal infarct cannot be ruled out	PRINT "Possible anteroseptal infarct" REASON: <i>30 ms Q wave in V1-V4</i>
Anteroseptal infarct cannot be ruled out and if the test for anterior infarct or septal infarct is positive	PRINT "Probable anteroseptal infarct" REASON: <i>35 ms Q wave in V1-V4</i>
Anteroseptal infarct cannot be ruled out and either an unqualified anterior or septal infarct exists	PRINT "Anteroseptal infarct" REASON: <i>40+ ms Q wave in V1-V4</i>
A recent septal infarct or anterior infarct has been called	"Probably recent" will be appended to the anteroseptal infarct call
Anterior infarct is not recent and either a new septal infarct or anterior infarct exists	"Possibly acute" is appended to the anteroseptal infarct call
Anterior infarct is not new and the tests for septal infarct age undetermined and/or anterior infarct age undetermined are positive	"Of indeterminate age" is appended to the anteroseptal infarct call
The tests for both septal infarct old and anterior infarct old are positive	"Probably old" is appended to the anteroseptal infarct call

Lateral Infarct

SKIP TEST IF

The test for either arm lead reversal, ventricular rhythm, electronic ventricular pacemaker or ventricular preexcitation is positive

Criteria

IF	THEN
STM AND STE AMP > 200 μ V in V5 & V6 and STM and STE amplitude > 100 μ V in I & aVL and Alternate T amplitude $\geq$ 0 in I, aVL, V5 & V6	New lateral infarct is present
STM and STE amplitude > 50 μ V in I, aVL, V5 or V6 and Alternate T amplitude < 0 in I, aVL, V5 or V6	Recent lateral infarct is called
The criteria for new or recent lateral infarct are not met and STM < 30 μ V in I, aVL, V5 and V6 and alternate T amplitude > 0 in I, aVL, V5 or V6	Old lateral infarct is present
The tests for new, recent or old lateral infarct are negative	Qualifier "of indeterminate age:" will be used
Equivalent Q duration $\geq$ 30 ms in 2 leads of I/V5/V6 and test for Right Bundle Branch Block is positive or Equivalent Q duration $\geq$ 30 ms and Q amplitude $\geq$ 300 μ V in 2 leads of I/V5/V6	PRINT "Possible lateral infarct" REASON: <i>30 ms Q wave in I/aVL/V5/V6</i>
Equivalent Q duration $\geq$ 35 ms in 1 lead of I/V5/V6 and the test for "possible lateral infarct" is positive	PRINT "Probable Lateral infarct" REASON: <i>35 ms Q wave in I/V5/V6</i>
Equivalent Q duration $\geq$ 40 ms in 1 lead of I/V5/V6 and the test for lateral infarct is positive or the test for "possible lateral infarct" is positive and the tests for a new or recent lateral infarct are positive	PRINT "Lateral infarct" REASON: <i>40+ ms Q wave and/or ST/T abnormality in I/aVL/V5/V6</i>

Lateral Infarct Criteria (Continued)

IF	THEN APPEND
Lateral infarct is new	Possibly acute
Lateral infarct is recent	Probably recent
The age of the lateral infarct is undetermined	Of indeterminate age
Lateral infarct is old	Probably old

Anterolateral Infarct

Criteria

IF	THEN
Both an anterior infarct and a lateral infarct "cannot be ruled out"	PRINT "Possible anterolateral infarct" REASON: 30 ms Q wave in I/aVL/V3-V6
The tests for anterior infarct or lateral infarct are positive	PRINT "Probable anterolateral infarct" REASON: 35 ms Q wave in I/aVL/V3-V6
The tests for an unqualified anterior infarct or lateral infarct are positive	PRINT "Anterolateral infarct" REASON: 40+ ms Q wave in I/aVL/V3-V6
The test for either a recent lateral infarct or anterior infarct is positive	"Probably recent" is appended to the anterolateral infarct statement
The infarct is not a recent anterolateral infarct and the test for a new lateral infarct or anterior infarct is positive	"New" anterolateral infarct is present "Probably acute" is appended to the statement
The infarct is not a new anterolateral infarct and the tests for "age undetermined" lateral infarct and/or an "age undetermined" anterior infarct are positive	"Age undetermined" anterolateral infarct is present "of indeterminate age" is appended to the statement
Both the lateral infarct and anterior infarct are qualified as "old"	Anterolateral infarct call will be qualified as "probably old"

Inferior Infarct

SKIP TEST IF

The test for either arm lead reversal, ventricular rhythm, electronic ventricular pacemaker, ventricular preexcitation or left bundle branch block is positive

Criteria

IF	THEN
STM and STE amplitude $> 100 \mu\text{V}$ in 2 leads of II/III/aVF or STM and STE amplitude $> 75 \mu\text{V}$ in 2 leads of II/III/aVF and STM amplitude $< -50 \mu\text{V}$ in 2 leads of V1/V2/V3 and QRS duration $< 120 \text{ ms}$ and Alternate T amplitude ≥ 0 in 2 leads of II/III/aVF	"New" inferior infarct is present
STM and STE amplitude $> 50 \mu\text{V}$ in 2 leads of II/III/aVF and Alternate T amplitude < 0 in 2 leads of II/III/aVF	"Recent" inferior infarct is present
Inferior infarct is not new or recent and STM amplitude $< 30 \mu\text{V}$ in 2 leads of II/III/aVF and Alternate T amplitude ≥ 0 in 2 leads of II/III/aVF	Inferior infarct is "old"
inferior infarct is not new, recent, or old	Qualifier "of indeterminate age" will be used
Equivalent Q duration $\geq 30 \text{ ms}$ in II or aVF Q amplitude in lead I $<$ Q amplitude in lead II or Q amplitude in lead I $<$ Q amplitude in aVF	PRINT "Possible inferior infarct" REASON: <i>30 ms Q wave in II/aVF</i>
Equivalent Q duration $\geq 35 \text{ ms}$ in II or aVF and an inferior infarct cannot be ruled out	PRINT "Probable inferior infarct" REASON: <i>35 ms Q wave in II/aVF</i>
Inferior infarct cannot be ruled out and Equivalent Q duration $\geq 40 \text{ ms}$ in II or aVF or The test for a new or recent Inferior infarct is positive	PRINT "Inferior infarct" REASON: <i>40+ ms Q wave and/or ST/T abnormality in II/aVF</i>

Inferior Infarct Criteria (Continued)

IF	THEN
QA > S amplitude in 1 lead of II & aVF	Suppress Abnormal left Axis Deviation
Inferior infarct is "new"	Append "possibly acute"
Inferior infarct is "recent"	Append "probably recent"
Age of the inferior infarct is undetermined	Append "of indeterminate age"
Inferior infarct is "old"	Append "probably old"

Inferior Infarct with Posterior Extension

SKIP TEST IF
The test for an inferior infarct is negative
The test for Right Bundle Branch Block is positive
A Q-wave is present in V1 or V2

Criteria

IF	THEN
R duration $\geq$ 40 ms in V1 & V2	Append "with posterior extension"
or	"prominent R Wave in V1/V2"
R duration $\geq$ 35 ms and QRS net amplitude > 0 in V1 or V2	to the inferior infarct statement
or	
R duration $\geq$ 30 ms and QRS net amplitude > 0 in V1 and V2	

InfarctSuppressions

Criteria

IF	THEN
The test for inferior infarct, lateral infarct, anteroseptal infarct or septal infarct is positive	Suppress left axis deviation, incomplete left bundle branch block, intraventricular conduction delay
The test for anteroseptal infarct or a lateral infarct is positive	Suppress pulmonary disease

9. Adult ST Elevation

ST Segment Elevation

SKIP TEST IF

The test for either arm lead reversal, ventricular rhythm, electronic ventricular pacemaker, ventricular preexcitation, right bundle branch block, left bundle branch block, marked intraventricular conduction delay, myocardial infarction or left ventricular hypertrophy with repolarization is positive

Criteria

IF	THEN
STJ/STM/STE all $\geq 50 \mu\text{V}$ and T is not upward inflected in 2 leads of I, II, III, aVF, V3-V6	PRINT "Nonspecific ST elevation" REASON: <i>0.05+ mV ST elevation</i>

Early Repolarization

SKIP TEST IF

Corrected QT interval > 460 ms in males or > 470 ms in females

The test for arm lead reversal, ventricular rhythm, electronic ventricular pacemaker, ventricular preexcitation, myocardial infarction, right bundle branch block, left bundle branch block, marked intraventricular conduction delay or left ventricular hypertrophy is positive

Criteria

IF	THEN
Count of leads V1-V6 for which STJ and STM amplitude $> 75 \mu\text{V}$ plus count of leads I, II, III, aVL, aVF for which STJ & STM $> 50 \mu\text{V}$ exceeds 2 and sum of STJ amplitudes $> 450 \mu\text{V}$ for leads passing above test	PRINT "ST elevation, consistent with injury, pericarditis, or early repolarization" REASON: <i>ST elevation w/o normally leads inflected T wave</i>
ST elevation is present, per the above conditions and more than 1/2 of the leads passing ST elevation test above also have well-inflected T waves	PRINT "ST elevation, probably early repolarization" REASON: <i>ST elevation with normally inflected T wave</i>
Above count > 5 and sum $> 450 \mu\text{V}$	PRINT "Early repolarization" REASON: <i>ST elevation with normally inflected T wave</i>

Pericarditis

SKIP TEST IF

The test for arm lead reversal, ventricular rhythm, electronic ventricular pacemaker, ventricular preexcitation, myocardial infarction, right bundle branch block, left bundle branch block, marked intraventricular conduction delay or left ventricular hypertrophy is positive

Criteria

IF	THEN
4 times STJ & T amplitude & T amplitude > 0 in at least 4 leads of I, II, V4-V6 and STJ and STM amplitude > -100 μ V in all leads except aVR and count of leads I, II, aVF with STJ and STM amplitude > 75 μ V plus count of leads V2-V6 with STJ and STM amplitude > 90 μ V is $\geq$ to 5	PRINT "Possible acute pericarditis – exclude acute MI" REASON: <i>Marked ST elevation w/o normally inflected T wave</i>
Possible acute pericarditis is present and count of leads I, II, aVF with STJ and STM amplitude > 90 μ V plus count of leads V2-V6 with STJ and STM amplitude > 110 μ V is $\geq$ to 5	PRINT "Acute pericarditis – exclude acute MI" REASON: <i>Marked ST elevation w/o normally inflected T wave</i>

Anterior and Septal Epicardial Injury

SKIP TEST IF

The test for pericarditis is positive

DEFINE

ST LIMIT = 300 μ V

(add 100 μ V for any precordial lead with net QRS amplitude < 0)

Criteria

IF	THEN
STJ amplitude > ST LIMIT/2 in V1 and V2 and T is not upward inflected V1 or V2 or 6 times STJ amplitude > QRS deflection in V1 and V2 or the test for septal infarct is negative and the tests for left ventricular hypertrophy, ventricular rhythm, electronic ventricular pacemaker, ventricular preexcitation, left bundle branch block, right bundle branch block and intraventricular conduction block are negative or R amplitude > 1.5 times S amplitude in V1 and V2	PRINT "ST elevation, consider septal injury" REASON: <i>Marked ST elevation w/o normally inflected T wave in V1/V2</i>
The test for "ST elevation, consider septal injury" is positive and 4 times STJ amplitude > QRS deflection in V1 and V2 or STJ amplitude > STE amplitude in V1 and V2 and STE amplitude > 200 μ V in V1 and V2	PRINT "Marked ST elevation, consider septal injury" REASON: <i>Marked ST elevation w/o normally inflected T wave in V1/V2</i>

Anterior and Septal Epicardial Injury Criteria (Continued)

IF	THEN
STJ amplitude > ST LIMIT/2 and T is not upward inflected in 2 leads of V2-V5 or STJ amplitude > ST LIMIT/2 2 leads of V2-V5 and STM amplitude < -50 μV in 2 leads of V5, V6, II, AVF, III or 6 times STJ amplitude > QRS deflection in 2 leads of V2-V5 and the test for anterior infarct is negative and the tests for left ventricular hypertrophy, ventricular rhythm, electronic ventricular pacemaker, ventricular preexcitation, left bundle branch block, right bundle branch block and intraventricular conduction block are negative or R amplitude > 1.5 times S amplitude in 3 leads of V2-V5	PRINT "ST elevation, consider anterior injury" REASON: <i>Marked ST elevation w/o normally inflected T wave in V2-V5</i>
The test for "ST elevation, consider anterior injury" is positive and 4 times STJ amplitude > QRS deflection in 2 leads of V2-V5 or STJ amplitude > STE amplitude or T amplitude < 0 and STM amplitude > 200 μV in 2 leads of V2, V3, V4 and the test for anterior infarct is negative	PRINT "Marked ST elevation, consider anterior injury" REASON: <i>Marked ST elevation w/o normally inflected T wave in V2-V5</i>
The test for a possible anterolateral epicardial injury is positive and the test for possible anterior and possible septal epicardial injury is positive	PRINT "ST elevation, consider anteroseptal injury" REASON: <i>Marked ST elevation w/o normally inflected T wave in V1-V4</i>
The test for a possible anteroseptal epicardial injury is positive and additional criteria substantiates an anterior injury or septal injury	PRINT "Marked ST elevation, consider anteroseptal injury" REASON: <i>Marked ST elevation w/o normally inflected T wave in V1-V4</i>

Lateral Epicardial Injury

SKIP TEST IF

The test for pericarditis is positive

Criteria

IF	THEN
STJ amplitude $> \text{ST LIMIT}/2$ and T is not upward inflected in 2 leads of I, aVL, V5, V6 or STJ amplitude $> \text{ST LIMIT}/2$ in 2 leads of I, aVL, V5, V6 and STM amplitude $< -50 \mu\text{V}$ in 2 leads of V1, V2, V3, III, aVR or 6 times STJ amplitude $>$ QRS deflection in 4 leads of I, aVL, V5, V6 and the test for a lateral infarct is negative and the tests for left ventricular hypertrophy, arm lead reversal, ventricular rhythm, electronic ventricular pacemaker, ventricular preexcitation, left bundle branch block, right bundle branch block and intraventricular conduction block are negative or R amplitude > 1.5 times S amplitude in 3 leads of I, aVL, V5 or V6	PRINT "ST elevation, consider lateral injury" REASON: <i>Marked ST elevation w/o normally inflected T wave in I/aVL/V5/V6</i>
The test for "ST elevation, consider lateral injury" is positive and 4 times STJ amplitude $>$ QRS deflection in 2 leads of I, aVL, V5, V6 or STJ amplitude $>$ STE amplitude and STE amplitude $> 200 \mu\text{V}$ in 2 leads of I, aVL, V5, V6 and the test for lateral infarct is negative	PRINT "Marked ST elevation, consider lateral injury" REASON: <i>Marked ST elevation w/o normally inflected T wave in I/aVL/V5/V6</i>

Lateral Epicardial Injury Criteria (Continued)

IF	THEN
The test for both possible anterior and lateral injury is positive	PRINT "ST elevation, consider anterolateral injury" REASON: <i>Marked ST elevation w/o normally inflected T wave in V3-V6</i>
The test for possible anterolateral epicardial injury is positive and the test for anterior and/or lateral injury is positive	PRINT "Marked ST elevation, consider anterolateral injury" REASON: <i>Marked ST elevation w/o normally inflected T wave in V3-V6</i>

Inferior Epicardial Injury

SKIP TEST IF

The test for pericarditis is positive

Criteria

IF	THEN
STJ amplitude $> \text{ST LIMIT}/2$ in 2 leads of II, III, aVF while T is not upward inflected in II, III or aVF or while STM amplitude $< -50 \mu\text{V}$ in 2 leads of V1-V3 or 6 times STJ amplitude $>$ QRS deflection in 2 leads of II, III, aVF and STJ amplitude $> 50 \mu\text{V}$ in 2 leads of II, III, aVF and STM amplitude $> 50 \mu\text{V}$ in 2 leads of II, III, aVF and the test for inferior infarct is negative and and the tests for left ventricular hypertrophy, arm lead reversal, ventricular rhythm, electronic ventricular pacemaker, ventricular preexcitation, left bundle branch block, right bundle branch block and intraventricular conduction block are negative or R amplitude > 1.5 times S amplitude in 2 leads of II, III, aVF	PRINT "ST elevation, consider inferior injury" REASON: <i>Marked ST elevation w/o normally inflected T wave in II/aVF</i>

Inferior Epicardial Injury Criteria (Continued)

IF	THEN
The test for "ST elevation, consider inferior injury" is positive and 4 times STJ amplitude > deflection in 2 leads of II, III, aVF or STJ amplitude > STE amplitude in 2 leads of II, III, aVF and STE amplitude > 100 μ V in 2 leads of II, III, aVF and the tests for left ventricular hypertrophy, arm lead reversal, ventricular rhythm, electronic ventricular pacemaker, ventricular preexcitation, left bundle branch block, right bundle branch block and intraventricular conduction block are negative and the test for inferior infarct is negative	PRINT "Marked ST elevation, consider inferior injury" REASON: <i>Marked ST elevation w/o normally inflected T wave in II/aVF</i>

10. Adult ST Depression

Minimal and Moderate ST Depression

SKIP TEST IF

Any test for arm lead reversal, ventricular rhythm, electronic ventricular pacemaker, ventricular preexcitation, right bundle branch block, left bundle branch block, marked intraventricular conduction delay, left or right ventricular hypertrophy with repolarization, or pericarditis is positive

Any test for epicardial injury is positive Any

test myocardial infarction is positive

Criteria

IF	THEN
STJ amplitude $< -100 \mu\text{V}$ and STE amplitude ≥ 0 in 2 Leads (except aVR and III)	PRINT "Junctional ST depression, consider normal variant" REASON: <i>0.1+ mV junctional ST depression</i>
STJ amplitude $< -100 \mu\text{V}$ and STE amplitude < 0 and STE amplitude $\geq$ STJ amplitude / 2 in 2 leads (except aVR and III)	PRINT "Marked junctional ST depression" REASON: <i>Junctional depression with weak upslope</i>
STJ/STM/STE amplitude all $< -25 \mu\text{V}$ in 2 leads (except aVR and III)	PRINT "Minimal ST depression" REASON: <i>0.025+ mV ST depression</i>
STM amplitude $< -50 \mu\text{V}$ and STE amplitude < 0 or STJ/STM/STE amplitude all $< -50 \mu\text{V}$ in 2 leads (except aVR and III)	PRINT "Moderate ST depression" REASON: <i>0.05+ mV ST depression</i>

Minimal ST depression and moderate junctional depression with upward sloping ST segment cause a borderline classification; the more pronounced levels give an abnormal statement. No suggestion is provided for the possible cause of the ST depression, e.g. digitalis effect.

Subendocardial Injury

SKIP TEST IF

Any test for epicardial injury is positive

Any test acute or recent myocardial infarction is positive

Criteria if a test for arm lead reversal, ventricular rhythm, electronic ventricular pacemaker, ventricular preexcitation, left bundle branch block, marked intraventricular conduction delay, left ventricular hypertrophy with repolarization, or pericarditis is positive

IF	THEN
STM < -100 μ V and R amplitude > 1.5 times S amplitude in 3 leads (except aVR and III)	PRINT "ST depression, consider subendocardial injury" REASON: <i>0.1+ mV ST depression</i>
STM < -200 μ V and R amplitude > 1.5 times S amplitude in 3 leads (except aVR and III)	PRINT "Marked ST depression, consider subendocardial injury" REASON: <i>0.2+ mV ST depression</i>

Criteria in other cases

IF	THEN
STJ/STM/STE all < -100 μ V in 2 leads (except aVR and III and except V1/V2 if right bundle branch block is present or right ventricular hypertrophy with repolarization is present)	PRINT "ST depression, consider subendocardial injury" REASON: <i>0.1+ mV ST depression</i>
STJ/STM/STE all < -200 μ V in 2 leads (except aVR and III and except V1/V2 if right bundle branch block is present or right ventricular hypertrophy with repolarization is present)	PRINT "Marked ST depression, consider subendocardial injury" REASON: <i>0.2+ mV ST depression</i>

11. Adult T Wave Abnormalities

T Wave Abnormality, Ischemia

SKIP TEST IF

Arm lead reversal, ventricular rhythm, electronic ventricular pacemaker, ventricular preexcitation, left bundle branch block, intraventricular conduction block, left ventricular hypertrophy with repolarization, right ventricular hypertrophy with repolarization, subendocardial injury, ST elevation or pericarditis is (are) true

Any test for acute or recent myocardial infarction is positive

Criteria

IF	THEN
The test for anteroseptal infarct is negative and the test for right ventricular hypertrophy with repolarization is negative and Alternate T amplitude $\leq -100 \mu\text{V}$ in 2 leads of V2/V3/V4 if RBBB is not present or $\leq -300 \mu\text{V}$ in V3 and V4 if RBBB is present	PRINT "Moderate T wave abnormality, consider anterior ischemia" REASON: <i>-0.1+ mV T wave in V3/V4</i>
The test for anterior ischemia is positive and Alternate T amplitude $< -500 \mu\text{V}$ in 1 lead of V2/V3/V4 (excluding V2 if right bundle branch block is present)	PRINT "Marked T wave abnormality, consider anterior ischemia" REASON: <i>-0.5+ mV T wave in V3/V4</i>
The test for lateral infarct is negative and Alternate T amplitude $< -100 \mu\text{V}$ in 2 leads of I/aVL/V4/V5/V6 (excluding aVL if R(aVL) $\leq 500 \mu\text{V}$)	PRINT "Moderate T wave abnormality, consider lateral ischemia" REASON: <i>-0.1+ mV T wave in I/aVL/V5/V6</i>
The test for lateral ischemia is positive and Alternate T amplitude $\leq -500 \mu\text{V}$ in 1 lead of I/aVL/V5/V6 (excluding aVL if R(aVL) $\leq 500 \mu\text{V}$)	PRINT "Marked T wave abnormality, consider lateral ischemia" REASON: <i>-0.5+ mV T wave in I/aVL/V5/V6</i>
The tests for both possible anterior and lateral ischemia are positive	PRINT "Moderate T wave abnormality, consider anterolateral ischemia" REASON: <i>-0.1+ mV T wave in V3-V6</i>
The test for possible anterolateral ischemia is positive and lateral and/or anterior ischemia is marked	PRINT "Marked T wave abnormality, consider anterolateral ischemia" REASON: <i>-0.5+ mV T wave in I/aVL/V3-V6</i>

T Wave Abnormality Ischemia Criteria (Continued)

IF	THEN
The test for nonspecific ST abnormalities is positive and the test for possible anterior ischemia and/or possible lateral ischemia is positive	Prefix "ST deviation and" to the T wave abnormality statement
The test for inferior infarct is negative and alternate T amplitude $< -100 \mu\text{V}$ in II or aVF (excluding aVF if net QRS amplitude < 0) and alternate T amplitude < 0 in II and aVF	PRINT "Moderate T wave abnormality, consider inferior ischemia" REASON: <i>-0.1+ mV T wave in II/aVF</i>
The test for inferior ischemia is positive and non-specific ST abnormalities are present	Prefix "ST deviation and" to the T wave abnormality statement
The test for possible inferior ischemia is positive and Alternate T amplitude $< -500 \mu\text{V}$ in II or aVF (excluding aVF if net QRS amplitude < 0)	PRINT "Marked T wave abnormality, consider inferior ischemia" REASON: <i>-0.5+ mV T wave in II/aVF</i>

T Wave Abnormality, Nonspecific

SKIP TEST IF

Arm lead reversal, ventricular rhythm, electronic ventricular pacemaker, ventricular preexcitation, right bundle branch block, left bundle branch block, intraventricular conduction block, left ventricular hypertrophy with repolarization, right ventricular hypertrophy with repolarization, subendocardial injury, ST elevation, pericarditis, myocardial infarct, possible anterior ischemia, possible lateral ischemia or possible inferior ischemia exist

DEFINE

TMIN=

1. $25 \mu\text{V} + \text{net QRS amplitude}/20$ if net amplitude ≥ 0
2. $25 \mu\text{V}$ if net QRS amplitude < 0

Criteria

IF	THEN
QRS axis - T axis > 60 and T axis < 0 or QRS - T axis < -60 and T axis > 90	PRINT "Abnormal QRS-T angle" REASON: <i>QRS-T axis difference > 60</i>
Count of I/II/aVL/aVF/V3-V6 with alternate T amplitude $< \text{TMIN}$ and R amplitude $> 500 \mu\text{V}$ is ≥ 2	PRINT "Nonspecific T wave abnormality"
Nonspecific ST abnormalities and nonspecific T- wave abnormalities exist and the test for tall T waves is negative	PRINT "Nonspecific ST & T wave abnormality"
T amplitude $> 1000 \mu\text{V}$ and T amplitude $> 1/2$ R amplitude in 3 leads of I/II/V1-V6 or T amplitude $> 1200 \mu\text{V}$ and T amplitude $> 1/2$ R amplitude in 2 leads of I/II/V1-V6	PRINT "Tall T waves, possible hyperkalemia"
"Non-specific T wave abnormality" causes a borderline classification; no attempt is made to identify a possible reason for T wave changes, e.g. digitalis effect.	

QT-Interval

Interpretative criteria are based on the QT-interval corrected for the heart rate, or, more precisely, corrected for the average RR-interval (QTc) in the 10 s recording. The Baxter QT correction utilizes a linear formula consistent with the general form determined in the Framingham heart study. In addition, QTc values calculated with other published correction formulas can be displayed by Baxter electrocardiographs. Calculations are executed according to the following formulas (units in seconds):

Linear correction: $QT_c = QT + 0.14 \cdot (1 - RR)$ Bazett correction: $QT_{cB} = QT / \sqrt{RR}$ Fridericia correction: $QT_{cF} = QT / RR^{1/3}$

Criteria 1

IF	THEN
$QT_c > 550 \text{ ms}$ or $QT > 550 \text{ ms}$ and Ventricular rate $\leq 100 \text{ bpm}$	PRINT "Prolonged QT Interval"

SKIP NEXT TEST IF
Arm lead reversal, ventricular rhythm, electronic ventricular pacemaker, ventricular preexcitation, right bundle branch block, left bundle branch block, intraventricular conduction block, left ventricular hypertrophy with repolarization, right ventricular hypertrophy with repolarization, subendocardial injury, ST elevation, pericarditis, myocardial infarct, possible anterior ischemia, possible lateral ischemia or possible inferior ischemia exist Ventricular rate $> 100 \text{ bpm}$

Criteria 2

IF	THEN
$QT_c > 470 \text{ ms}$ or $QT_c > 460 \text{ ms}$ and sex is male	PRINT "Prolonged QT interval"

12. Adult Brugada

Brugada

SKIP TEST IF

T amplitude < -1mV in any of V4, V5, and V6 Atrial
flutter is present
LBBB is present
QRS duration > 160ms Rate
> 120 BPM
More than 1 of V1-V3 has no R wave and an upsloping ST segment
More than 1 of V1-V3 has an R amplitude > 2.5 times the S amplitude

Criteria

IF	THEN
STJ $\geq 50 \mu\text{V}$ and ST segment is downsloping and STJ $\geq 200 \mu\text{V}$ in at least 1 of V1-V3	PRINT "Type 3 Brugada pattern (non-diagnostic)" REASON: <i>Coved/saddleback ST elevation > 0.1mV in 2 of V1-3</i>
STJ $\geq 150 \mu\text{V}$ and STE $\geq 100 \mu\text{V}$ and T amplitude > STM and STE in 2 of V1-V3 and STJ $\geq 200 \mu\text{V}$ in at least one of V1-V3	PRINT "Type 2 Brugada pattern (non-diagnostic)" REASON: <i>Saddleback ST elevation > 0.2mV with positive/biphasic T wave in 2 of V1-3</i>
STJ $\geq 150 \mu\text{V}$ and STM < STJ and STE < STM and T amplitude < 0 in 2 of V1-V3 and STJ $\geq 200 \mu\text{V}$ in at least one of V1-V3	PRINT "Type 1 Brugada pattern, exclude recent infarction, CABG, myocarditis, or drug effect" REASON: <i>Coved-type ST elevation > 0.2mV with negative T wave in 2 of V1-3</i>

13. Pediatric Criteria

Arm Lead Reversal and Dextrocardia

Criteria

IF	THEN
No Q in lead I and R amplitude < 150 μ V in lead I	PRINT "Arm leads reversed" REASON: <i>rS or Qr in I, P(III) > P(II), QRS axis > 90</i>
or	
Q amplitude > R amplitude in lead I and Maximum S amplitude > 150 μ V in lead I and P amplitude in lead III > P amplitude lead II and P axis > 90 and QRS axis > 90	

IF	THEN
If P axis ≥ 90 and P axis ≤ 180 and Maximum R amplitude < 500 μ V in V6 and Maximum S amplitude > R amplitude in V6 and P amplitude < 20 μ V in lead V6 and P' amplitude < -20 μ V in lead V6	PRINT "Dextrocardia"

Wolff-Parkinson-White

Criteria

IF	THEN
If Delta wave is present in some of V1/V2/V3/V4/V5/V6 and PR duration ≤ 119 ms and QRS duration ≥ 97 ms and Ventricular rate < 150 bpm	PRINT "Ventricular preexcitation/WPW" REASON: <i>Delta Waves</i>

Atrial Enlargement

Criteria

IF	THEN
Age $\geq$ 10 years and P amplitude $> 200 \mu\text{V}$ in any 1 lead of I/II/III/aVF/V1/V2 and P amplitude $> 150 \mu\text{V}$ in any 2 leads of I/II/III/aVF/V1/V2	PRINT "Possible right atrial enlargement" REASON: <i>0.2 mV P wave, Age $\geq$ 10 yr</i>
P amplitude $> 250 \mu\text{V}$ in any 1 lead of I/II/III/aVF/V1/V2 and P amplitude $> 200 \mu\text{V}$ in any 2 leads of I/II/III/aVF/V1/V2	PRINT "Right atrial enlargement" REASON: <i>0.25 mV P wave</i>
P' amplitude $< -70 \mu\text{V}$ and negative P wave area $\geq 400 \mu\text{V ms}$ in V1	PRINT "Possible left atrial enlargement"
P' amplitude $< -100 \mu\text{V}$ and negative P wave area $\geq 400 \mu\text{V/ms}$ in V1	PRINT "Left atrial enlargement"

Axis Deviation

Criteria

IF	THEN
QRS axis $<$ Minimum QRS axis for age	PRINT "Left axis deviation" REASON: <i>QRS axis $<$ [Minimum QRS axis for age]</i>
QRS axis $>$ Maximum QRS axis for age	PRINT "Right axis deviation" REASON: <i>QRS axis $>$ [Maximum QRS axis for age]</i>

Please see pediatric criteria table for **QRS Axis for Age** in Reference Summary. Axis deviation statements are omitted when subsequently identified diagnostic categories may be regarded as the probable cause of the axis deviation, e.g. right or left bundle branch conduction blocks.

14. Pediatric Conduction Abnormalities

Right Bundle Conduction

Criteria

IF	THEN
QRS duration $\geq$ Maximum QRS duration for age and R' amplitude $\geq 150 \mu\text{V}$ in V1 and R' duration $\geq 20 \text{ ms}$ in V1 and R' amplitude $> 4 \times \text{S' amplitude}$ in V1	PRINT "Right bundle branch block" REASON: <i>QRS $\geq$ [Maximum QRS duration for age], RSR' in V1</i>
QRS duration $\geq$ Maximum QRS duration for age and R amplitude $\geq 550 \mu\text{V}$ and no S wave is present in V1	PRINT "Right bundle branch block" REASON: <i>QRS $\geq$ [Maximum QRS duration for age], no S in V1</i>

Please see pediatric criteria table for **QRS Duration for Age** in Reference Summary.

Left Bundle Conduction

Criteria

IF	THEN
QRS axis ≤ -60	PRINT "Left anterior fascicular block" REASON: <i>QRS axis -60 to -90</i>
S duration $\leq 20 \text{ ms}$ in 3 of I/aVL/V5/V6 and Terminal QRS axis ≤ 90 and QRS duration $\geq$ Maximum QRS duration for age and R wave amplitude $\leq 450 \mu\text{V}$ and R wave duration $\leq 39 \text{ ms}$ in some of V1/V2/V3 or R wave amplitude $\geq 450 \mu\text{V}$ and R wave duration $\leq 39 \text{ ms}$ in some of V1/V2/V3 and QRS duration $> 135 \text{ ms}$	PRINT "Left bundle branch block" REASON: <i>QRS $\geq$ [Maximum QRS duration for age], terminal QRS leftward</i>

Please see pediatric criteria table for **QRS Duration for Age** in Reference Summary.

Ventricular Conduction Delay

Criteria

IF	THEN
The test for Right Bundle Branch Block is negative and The test for Left Bundle Branch Block is negative and The test for Left Anterior Fascicular Block is negative and QRS duration $\geq$ Maximum QRS Duration for age	PRINT "Ventricular Conduction Delay" REASON: <i>QRS duration $\geq$ [Maximum QRS Duration for age]</i>

Please see pediatric criteria table for **QRS Duration for Age** in Reference Summary.

15. Pediatric Hypertrophy

Right Ventricular Hypertrophy

SKIP TEST IF

Test for Right Bundle Branch Block is positive, or
 Test for Left Bundle Branch Block is positive, or Test
 for Ventricular Conduction Delay is positive

Criteria

Criteria statements for Right Ventricular Hypertrophy are printed only if the "Print reason" option on the electrocardiograph is turned on; otherwise, only the summary statements are printed.

IF	THEN
Age $\geq$ 1 month and S amplitude $\geq$ 1000 μ V in V6	PRINT REASON "RVH voltage criteria: $S(V6) > 1mV, 1mo-15yr$ " <i>NOTE: Final comment is "Borderline ECG"</i>
Age $\geq$ 1 month and R amplitude $\geq$ 2500 μ V in V2 and QRS deflection positive in V3R or V1	PRINT REASON "RVH voltage criteria: $R(V2) > 2.5mV, 1mo-15yr$ "
Age $\geq$ 1 month and maximum R amplitude/S amplitude < 1.2 in V6 and QRS deflection positive in V3R or V1	PRINT REASON "RVH voltage criteria: $R/S(V6) < 1.2, 1mo-15yr$ " <i>NOTE: Final comment is "Borderline ECG"</i>
Maximum R amplitude/S amplitude $<$ minimum V6 R/S amplitude ratio for Age <i>NOTE: for age $\geq 3yr$: and QRS deflection positive in V3R or V1</i>	PRINT REASON "RVH voltage criteria: $R/S(V6) <$ [Minimum V6 R/S amplitude ratio for age]"
Age $<$ 5 days and maximum R amplitude $>$ 2200 μ V in V3R or V1	PRINT REASON "RVH voltage criteria: $R(V3R/V1) < 2.2mV, < 5day$ " <i>NOTE: Final comment is "Borderline ECG"</i>
Age $\geq$ 5 days and age $<$ 30 days and maximum R amplitude $>$ 2200 μ V in V3R or V1	PRINT REASON "RVH voltage criteria: $R(V3R/V1) < 2.2mV, 5-30day$ "
Age $\geq$ 30 days and age $<$ 16 years and maximum R amplitude $>$ 1700 μ V in V3R or V1	PRINT REASON "RVH voltage criteria: $R(V3R/V1) < 1.7mV, 1mo-15yr$ "
Maximum R amplitude/maximum S amplitude $>$ maximum V3R/V1 R/S amplitude ratio for Age and R-amplitude in V3R/V1 $\geq$ 300 μ V	PRINT REASON "RVH voltage criteria: $R/S(V3R/V1) >$ [Maximum V3R/V1 R/S amplitude ratio for Age]"
Age $<$ 3 months and R' amplitude $\geq$ 2000 μ V and R' duration $\geq$ 20 ms and no S' in V3R or V1	PRINT REASON "RVH voltage criteria: $R'(V3R/V1) > 2mV, < 3mo$ "

Right Ventricular Hypertrophy Criteria (Continued)

IF	THEN
Age $\geq$ 2 months and Age $<$ 1 year and R' amplitude $\geq$ 1600 μ V and R' duration $\geq$ 12 ms and no S' in V3R or V1	PRINT REASON "RVH voltage criteria: <i>R'(V3R/V1) > 1.6 mV, 2-11mo</i> "
Age $\geq$ 1 year and R' amplitude $>$ 1000 μ V and R' duration $\geq$ 12 ms and R' amplitude $>$ R amplitude and R' amplitude $>$ R amplitude and no S' in V3R or V1	PRINT REASON "RVH voltage criteria: <i>R'(V3R/V1) > 1 mV, 1-15yr</i> "
Age $<$ 5 days and QRS with only R-wave and R amplitude $\geq$ 1000 μ V in V3R or V1	PRINT REASON "RVH voltage criteria: <i>Pure R(V3R/V1) > 1 mV, <5day</i> " NOTE: Final comment is "Borderline ECG"
Age $\geq$ 5 days and age $<$ 30 days and QRS with only R-wave and R amplitude $\geq$ 1000 μ V in V3R or V1	PRINT REASON "RVH voltage criteria: <i>Pure R (V3R/V1) > 1 mV, 5-30day</i> "
Age $\geq$ 30 days and QRS with only R-wave and R amplitude $\geq$ 500 μ V in V3R or V1	PRINT REASON "RVH voltage criteria: <i>Pure R (V3R/V1) > 0.5 mV, 1mo-15yr</i> "
Age $<$ 30 days and Q amplitude $\geq$ 70 μ V and Q duration $\geq$ 20 ms and R amplitude $\geq$ 500 and R amplitude $>$ S amplitude in V3R or V1	PRINT REASON "RVH voltage criteria: <i>QR in V3R/V1, < 1mo</i> "
Age $\geq$ 30 days Q amplitude $\geq$ 70 μ V and Q duration $\geq$ 20 ms and R amplitude $\geq$ 500 and R amplitude $>$ S amplitude in V3R or V1	PRINT REASON "RVH voltage criteria: <i>QR in V3R/V1, 1mo-15yr</i> "

Right Ventricular Hypertrophy Criteria (Continued)

IF	THEN
Age > 5 days and age < 5 years and T amplitude $\geq 100 \mu\text{V}$ and T amplitude > 2 x STM amplitude in V3R or V1	PRINT REASON "RVH T wave criteria: <i>T upright in V3R/V1, 5day-4yr</i> "
Age ≥ 5 years and age < 9 years and T amplitude $\geq 150 \mu\text{V}$ and T amplitude > 2 x STM amplitude in V3R or V1	PRINT REASON "RVH T wave criteria: <i>T upright in V3R/V1, 5-8yr</i> " NOTE: Final comment is "Borderline ECG"

Please see pediatric criteria table for **V6 R/S Amplitude Ratio for Age** in Reference Summary. Additionally, the following definitions are utilized: **STJ** = ST segment amplitude at QRS offset; **STM** = ST segment amplitude at ST segment midpoint; **STE** = ST segment amplitude at ST segment endpoint.

Summary Statement

Depending upon which RVH criteria are satisfied, a summary statement reflecting the different criteria and their degree will be generated. Summary statements for RVH include the following:

Possible Right Ventricular Hypertrophy [Voltage Criteria Only] Possible Right Ventricular Hypertrophy [T wave Changes] Possible Right Ventricular Hypertrophy [Axis Criteria Only]

NOTE: Final comment is "Borderline ECG"

Probable Right Ventricular Hypertrophy [Voltage Criteria Only] Probable Right Ventricular Hypertrophy [T wave Changes]

Right Ventricular Hypertrophy [Severe Voltage Criteria]

NOTE: R/S(V3R/V1) > [Maximum V3R/V1 R/S amplitude ratio for Age], 1-11 mo; Pure R (V3R/V1) > 0.5 mV, 1mo-15yr; QR in V3R/V1, 1mo-15yr

Right Ventricular Hypertrophy [T wave Changes & RAD for Age] Right Ventricular Hypertrophy [Voltage & T wave Changes] Right Ventricular Hypertrophy [Voltage & RAD for Age]

Right Ventricular Hypertrophy [Voltage & RAE]

Right Ventricular Hypertrophy [Voltage, RAD for Age & T wave Changes]

Consider Associated Right Ventricular Hypertrophy [R(V1) > 1.5 mV & LVH] Consider Biventricular Hypertrophy [R+S > 6mV in 2 of V2-V4]

NOTE: Final comment is "Borderline ECG"

Left Ventricular Hypertrophy

SKIP TEST IF

Test for Left Bundle Branch Block is positive, or Test
for Right Bundle Branch Block is positive, or
Test for Ventricular Conduction Delay is positive

Criteria

Criteria statements for Left Ventricular Hypertrophy are printed only if the "Print reason" option on the electrocardiograph is turned on; otherwise, only the summary statements are printed.

IF	THEN
Q amplitude $\geq 600 \mu\text{V}$ and R amplitude $\geq 1000 \mu\text{V}$ in V5 or V6	PRINT REASON "LVH voltage criteria: $Q > 0.6\text{mV} \& R > 1\text{ mV in V5/V6}$ " <i>NOTE: Final comment is "Borderline ECG"</i>
R amplitude $\geq 3000 \mu\text{V}$ in I, II, aVL, or aVF	PRINT REASON "LVH voltage criteria: $R > 3\text{ mV in 1 of I/II/aVL/aVF}$ " <i>NOTE: Final comment is "Borderline ECG"</i>
S amplitude $\geq 3500 \mu\text{V}$ in V2	PRINT REASON "LVH voltage criteria: $S(V2) > 3.5\text{ mV}$ " <i>NOTE: Final comment is "Borderline ECG"</i>
R amplitude $\geq 2300 \mu\text{V}$ in V6 and T amplitude $\leq 1/10$ of R amplitude in V6	PRINT REASON "LVH voltage criteria: $R(V6) > 2.3\text{ mV} \& \text{small T}$ " <i>NOTE: Summary statement is "Borderline ECG"</i>
R amplitude $\geq 3000 \mu\text{V}$ in V6	PRINT REASON "LVH voltage criteria: $R(V6) \geq 3.0\text{ mV}$ "
R amplitude $\geq 2300 \mu\text{V}$ and Q amplitude $\geq 600 \mu\text{V}$ in V6	PRINT REASON "LVH voltage criteria: $R(V6) > 2.3\text{ mV} \& Q(V6) > 0.6\text{mV}$ "
R amplitude of V5 + S amplitude of V1 $\geq 3500 \mu\text{V}$ and T amplitude $\leq 1/10$ of R amplitude in V6	PRINT REASON "LVH voltage criteria: $S(V1) + R(V5) \geq 3.5\text{ mV} \& \text{small T}$ " <i>NOTE: Final comment is "Borderline ECG"</i>
R amplitude of V5 + S amplitude of V1 $\geq 4500 \mu\text{V}$	PRINT REASON "LVH voltage criteria: $S(V1) + R(V5) \geq 4.5\text{ mV}$ "
STM $\leq -10 \mu\text{V}$ and down sloping ST-segment and T amplitude $\leq -50 \mu\text{V}$ in 2 of I/aVL/V4/V5/V6	PRINT REASON "LVH ST-T criteria: $ST < -0.01\text{ mV} \& T < -0.05\text{ mV in 2 of I/aVL/V4-6}$ "

Summary Statement

Depending upon which LVH criteria are satisfied, a summary statement reflecting the different criteria and their degree will be generated. Summary statements for LVH include the following:

Possible Left Ventricular Hypertrophy [Voltage Criteria Only] Possible Left Ventricular Hypertrophy [T wave Changes]

NOTE: Final comment is "Borderline ECG"

Probable Left Ventricular Hypertrophy [Severe Voltage Criteria] Probable Left Ventricular Hypertrophy [LAD for Age & ST-T Changes]

Probable Left Ventricular Hypertrophy, mild, or diastolic overload [moderate voltage criteria and ST-elevation]

Left Ventricular Hypertrophy [Voltage Criteria & LAD for Age]

Left Ventricular Hypertrophy, probably mild, or diastolic overload [moderate voltage criteria and ST-elevation] Left

Ventricular Hypertrophy, Probably Severe, or Systolic Overload [Voltage Criteria & ST-T Rightward]

Consider Associated Left Ventricular Hypertrophy [$Q > 0.1\text{mV}$ & $R > 1\text{mV}$ in V6 & $R+S > 3.5\text{ mV}$ in V4 with RVH]

Consider Biventricular Hypertrophy [$R+S > 6\text{mV}$ in 2 of V2-V4]

NOTE: Final comment is "Borderline ECG"

16. Pediatric ST Segment Abnormalities

ST Segment Elevation

SKIP TEST IF

The test for either right bundle branch block, left bundle branch block, is positive.

Criteria

IF	THEN
Lesser of STJ or STM $\geq 150 \mu\text{V}$ in 2 leads of V2,V3,V4,V5,V6	PRINT "Anterior ST elevation, consider normal variant" REASON: <i>ST > 0.15 mV in 2 of V2-V5</i>
STJ/STM/STE all $\geq 150 \mu\text{V}$ in 1 of II/III/aVF and STJ/STM/STE all $\geq 100 \mu\text{V}$ in 2 of II/III/aVF	PRINT "Inferior ST elevation, consider normal variant" REASON: <i>ST > 0.15 mV in 1 of II/III/aVF</i>
Lesser of STJ or STM $\geq 150 \mu\text{V}$ in 2 leads of I/aVL/V6	PRINT "Anterolateral ST elevation, consider normal variant" REASON: <i>ST > 0.15 mV in 2 of I/aVL/V6</i>
Lesser of STJ or STM $\geq 150 \mu\text{V}$ in 2 leads of I/aVL/V6 and Test is positive for any LVH criteria	PRINT "Anterolateral ST elevation, probably secondary to LVH" REASON: <i>ST > 0.15 mV in 2 of I/aVL/V6 & LVH</i>

ST Segment Depression

SKIP TEST IF

The test for either right bundle branch block, left bundle branch block, is positive.

Criteria

IF	THEN
STJ/STM < -200 μ V in 1 of V2/V3/V4/V5	PRINT "Anterior ST depression, consider subendocardial injury" REASON: <i>ST < -0.2mV in 1 of V2-V5</i>
STJ/STM < -200 μ V in 1 of II/III/aVF	PRINT "Inferior ST depression, consider subendocardial injury" REASON: <i>ST < -0.2mV in 1 of II/III/aVF</i>
STJ/STM < -200 μ V in 1 of I/aVL/V6 and STJ/STM < -200 μ V in 1 of V2/V3/V4/V5	PRINT "Anterolateral ST depression, consider subendocardial injury" REASON: <i>ST < -0.2mV in 1 of I/aVL/V2-6</i>
STJ/STM < -200 μ V in 1 of I/aVL/V6 and STJ/STM < -200 μ V in 1 of V2/V3/V4/V5 a test for LVH is positive	PRINT "Anterolateral ST depression, probably secondary to LVH" REASON: <i>ST < -0.2mV in 1 of I/aVL/V2-V6 and LVH</i>

17. Pediatric T Wave Abnormalities

T Wave Abnormality, Ischemia

SKIP TEST IF

Age < 12

Any test for right bundle branch block, left bundle branch block or intraventricular conduction delay is positive.

Criteria

IF	THEN
T amplitude $\leq -10 \mu\text{V}$ or T' amplitude $\leq -10 \mu\text{V}$ in 2 of V1/V2/V3	PRINT "Minimal anterior T wave changes" REASON: $T < -0.01 \text{ mV}$ in 2 of V1-V3
T amplitude $\leq -10 \mu\text{V}$ or T' amplitude $\leq -10 \mu\text{V}$ in 2 of V1/V2/V3	PRINT "Minimal anterior T wave changes" REASON: $T < -0.01 \text{ mV}$ in V1-V5
and	
T amplitude $\leq -10 \mu\text{V}$ or T' amplitude $\leq -10 \mu\text{V}$ in 1 of V4/V5	
T amplitude $\leq -100 \mu\text{V}$ or T' amplitude $\leq -100 \mu\text{V}$ in 2 of V1/V2/V3	PRINT "Moderate anterior T wave changes" REASON: $T < -0.1 \text{ mV}$ in 2 of V1-V3
T amplitude $\leq -100 \mu\text{V}$ or T' amplitude $\leq -100 \mu\text{V}$ in 2 of V1/V2/V3	PRINT "Moderate anterior T wave changes" REASON: $T < -0.1 \text{ mV}$ in V1-V5
and	
T amplitude $\leq -100 \mu\text{V}$ or T' amplitude $\leq -100 \mu\text{V}$ in 1 of V4/V5	
T amplitude $\leq -500 \mu\text{V}$ or T' amplitude $\leq -500 \mu\text{V}$ in 2 of V1/V2/V3	PRINT "Anterior T wave changes" REASON: $T < -0.5 \text{ mV}$ in 2 of V1-V3
T amplitude $\leq -500 \mu\text{V}$ or T' amplitude $\leq -500 \mu\text{V}$ in 2 of V1/V2/V3	PRINT "Anterior T wave changes" REASON: $T < -0.5 \text{ mV}$ in V1-V5
and	
T amplitude $\leq -500 \mu\text{V}$ or T' amplitude $\leq -500 \mu\text{V}$ in 1 of V4/V5	

T Wave Abnormality Ischemia Criteria (Continued)

IF	THEN
T amplitude $\leq -1000 \mu\text{V}$ or T' amplitude $\leq -1000 \mu\text{V}$ in 2 of V1/V2/V3	PRINT "Marked anterior T wave changes, consider ischemia" REASON: $T < -1 \text{ mV}$ in 2 of V1-V3
T amplitude $\leq -1000 \mu\text{V}$ or T' amplitude $\leq -1000 \mu\text{V}$ in 2 of V1/V2/V3	PRINT "Marked anterior T wave changes, consider ischemia" REASON: $T < -1 \text{ mV}$ in V1-V5
and	
T amplitude $\leq -1000 \mu\text{V}$ or T' amplitude $\leq -1000 \mu\text{V}$ in 1 of V4/V5	
T amplitude $\leq -1000 \mu\text{V}$ or T' amplitude $\leq -1000 \mu\text{V}$ in 2 of V1/V2/V3	PRINT "Consider anterior ischemia, probably secondary to RVH" REASON: $T < -1 \text{ mV}$ in V1-V3 & RVH
and	
test is positive for any RVH criteria	
T amplitude $\leq -100 \mu\text{V}$ or T' amplitude $\leq -100 \mu\text{V}$ in 2 of II/III/aVF	PRINT "Moderate inferior T wave changes" REASON: $T < -0.1 \text{ mV}$ in 2 of II/III/aVF
T amplitude $\leq -500 \mu\text{V}$ or T' amplitude $\leq -500 \mu\text{V}$ in 1 of II/III/aVF	PRINT "Inferior T wave changes" REASON: $T < -0.5 \text{ mV}$ in 1 of II/III/aVF
T amplitude $\leq -1000 \mu\text{V}$ or T' amplitude $\leq -1000 \mu\text{V}$ in 1 of II/III/aVF or	PRINT "Marked inferior T wave changes, consider ischemia" REASON: $T < -1 \text{ mV}$ in 1 of II/III/aVF or $T < -0.5 \text{ mV}$ in 2 of II/III/aVF
T amplitude $\leq -500 \mu\text{V}$ or T' amplitude $\leq -500 \mu\text{V}$ in 2 of II/III/aVF	
T amplitude $\geq 1000 \mu\text{V}$ or T' amplitude $\geq 1000 \mu\text{V}$ in 2 of I/aVL/V2/V3/V4/V5/V6	PRINT "Tall T-waves, consider normal variant" REASON: $T > 1 \text{ mV}$ in 2 of I/aVL/V2-V6
and	
test for LVH is negative	

T Wave Abnormality Ischemia Criteria (Continued)

IF	THEN
T amplitude $\leq -10 \mu\text{V}$ or T' amplitude $\leq -10 \mu\text{V}$ in 1 of I/aVL/V6 and T amplitude $\leq -10 \mu\text{V}$ or T' amplitude $\leq -10 \mu\text{V}$ in 2 of V1/V2/V3 and T amplitude $\leq -10 \mu\text{V}$ or T' amplitude $\leq -10 \mu\text{V}$ in 1 of V4/V5 and not T amplitude $\leq -1000 \mu\text{V}$ or T' amplitude $\leq -1000 \mu\text{V}$ in 2 of V1/V2/V3	PRINT "Moderate anterolateral T wave changes" REASON: $T < -0.01 \text{ mV in I/aVL/V2-V6}$
T amplitude $\leq -100 \mu\text{V}$ or T' amplitude $\leq -100 \mu\text{V}$ in 1 of I/aVL/V6 and T amplitude $\leq -100 \mu\text{V}$ or T' amplitude $\leq -100 \mu\text{V}$ in 2 of V1/V2/V3 and T amplitude $\leq -100 \mu\text{V}$ or T' amplitude $\leq -100 \mu\text{V}$ in 1 of V4/V5 and not T amplitude $\leq -1000 \mu\text{V}$ or T' amplitude $\leq -1000 \mu\text{V}$ in 2 of V1/V2/V3	PRINT "Moderate anterolateral T wave changes" REASON: $T < -0.1 \text{ mV in I/aVL/V2-V6}$

T Wave Abnormality Ischemia Criteria (Continued)

IF	THEN
T amplitude $\leq -100 \mu\text{V}$ or T' amplitude $\leq -100 \mu\text{V}$ in 1 of I/aVL/V6 and T amplitude $\leq -100 \mu\text{V}$ or T' amplitude $\leq -100 \mu\text{V}$ in 2 of V1/V2/V3 and T amplitude $\leq -100 \mu\text{V}$ or T' amplitude $\leq -100 \mu\text{V}$ in 1 of V4/V5 and not T amplitude $\leq -1000 \mu\text{V}$ or T' amplitude $\leq -1000 \mu\text{V}$ in 2 of V1/V2/V3 and a test is positive for any LVH criteria	PRINT "Consider anterolateral ischemia, probably secondary to LVH" REASON: $T < -0.1 \text{ mV}$ in I/aVL/V2-V6 & LVH
T amplitude $\leq -500 \mu\text{V}$ or T' amplitude $\leq -500 \mu\text{V}$ in 1 of I/aVL/V6 and T amplitude $\leq -500 \mu\text{V}$ or T' amplitude $\leq -500 \mu\text{V}$ in 2 of V1/V2/V3	PRINT "Anterolateral T wave changes, consider ischemia" REASON: $T < -0.5 \text{ mV}$ in 1 of I/aVL/V2-V6
T amplitude $\leq -500 \mu\text{V}$ or T' amplitude $\leq -500 \mu\text{V}$ in 1 of I/aVL/V6 and T amplitude $\leq -1000 \mu\text{V}$ or T' amplitude $\leq -1000 \mu\text{V}$ in 2 of V1/V2/V3	PRINT "Marked anterolateral T wave changes, consider ischemia" REASON: $T < -1 \text{ mV}$ in 1 of I/aVL/V2-V6

QT Prolongation

Interpretative criteria are based on the QT-interval corrected for the heart rate, or, more precisely, corrected for the average RR-interval (QTc) in the 10 s recording. The Baxter QT correction utilizes a linear formula consistent with the general form determined in the Framingham heart study. In addition, QTc values calculated with other published correction formulas can be displayed by Baxter electrocardiographs. Calculations are executed according to the following formulas (units in seconds):

Linear correction: $QTc = QT + 0.14 \cdot (1 - RR)$ Bazett correction: $QTcB = QT / \sqrt{RR}$ Fridericia correction: $QTcF = QT / RR^{1/3}$

Criteria 1

IF	THEN
QTc > 550 ms or QT > 550 ms and Ventricular rate ≤ Tachycardia limit	PRINT "Prolonged QT Interval"

SKIP NEXT TEST IF

Arm lead reversal, dextrocardia, ventricular rhythm, electronic ventricular pacemaker, ventricular preexcitation, right bundle branch block, left bundle branch block or intraventricular conduction block exist
Ventricular rate is above the Tachycardia limit.

Criteria 2

IF	THEN
QTc > 460 ms	PRINT "Prolonged QT Interval"

Brugada Pattern

The Brugada pattern seldom expresses at a young age, unless pharmacologically provoked. It would be unnecessarily alarming to provide for a statement for Brugada pattern at an age below 16 years.

18. Pediatric Tricuspid Atresia

Tricuspid Atresia

Criteria

IF	THEN
Left axis deviation and Left ventricular hypertrophy and Right atrial enlargement	PRINT "Consider tricuspid atresia" REASON: <i>RAE + LAD + LVH</i>

19. Pediatric Endocardial Cushion Defect

Endocardial Cushion Defect

Criteria

IF	THEN
QRS Axis > -170 or QRS Axis < -30 and Q amplitude $\geq 80 \mu\text{V}$ and R amplitude $\geq 100 \mu\text{V}$ in aVL and Test for RVH or RBBB is true	PRINT "Consider endocardial cushion defect" REASON: <i>QRS -30 to -170, RVH or RSR' in V1</i>

20. Pediatric Atrial Septal Defect

Atrial Septal Defect

Criteria

IF	THEN
QRS Axis > 0 and	PRINT "Consider atrial septal defect"
QRS Axis ≤ 180 and	REASON: <i>QRS 1-180, RSR' in V1</i>
RSR' pattern in V1	

21. Reference Summary

Age Tables

The following tables should be used in reference to parameters that are stated as minimum or maximum “for age”. In the following, **d** indicates days, **mo** indicates months, and **yr** indicates years. On the bottom line, where relevant, are the adult references.

QRS Axis for Age

Age	QRS Axis Minimum (Left Axis Deviation Criteria)	QRS Axis Maximum (Right Axis Deviation Criteria)
< 6d	60	180
6 – 30d	60	160
1 – 2mo	40	135
3 – 5mo	20	135
6mo – 15yr	0	135
>= 16yr	-20	90

QRS Duration for Age

Age	QRS Duration
< 1yr	99ms
1 – 15yr	109ms
>= 16yr	119ms

Prolonged PR Duration, Bradycardia, and Tachycardia for Age

Age	PR Duration (ms)	Bradycardia (bpm)	Critical Bradycardia (BPM)	Tachycardia (bpm)	Critical Tachycardia (BPM)
< 1d	129	9 4	7 0	145	194
< 8d	129	1 0 0	7 5	175	119
< 1mo	129	1 1 5	9 0	190	219
< 3mo	139	1 2 4	9 0	190	219
< 1yr	139	1 1 0	9 0	178	209
< 3yr	159	9 8	7 0	163	199
< 5yr	159	6 5	5 0	132	179
< 8yr	169	6 5	4 5	115	159
< 12yr	179	6 0	4 5	107	149
< 16yr	179	6 0	4 5	102	149
>= 16yr	209	6 0	4 0	99	149

V6 R/S Amplitude Ratio for Age

Age	V6 R/S Amplitude Ratio
1 – 3mo	0.5
4 – 11mo	0.7
1 – 2yr	0.8
3 – 15yr	0.9

V1/V3R R/S Amplitude Ratio for Age

Age	V1/V3R R/S Amplitude Ratio
1 – 3mo	7
4 – 11mo	4.5
1 – 2yr	3
3 – 7yr	2.3
8 – 15yr	2

Conclusions – Rhythm Statements

Statement	Conclusions
Sinus rhythm	Normal ECG
Sinus tachycardia	Abnormal Rhythm ECG
Sinus bradycardia	Borderline ECG
Ectopic atrial rhythm	Abnormal Rhythm ECG
Ectopic atrial tachycardia	Abnormal Rhythm ECG
Ectopic atrial bradycardia	Abnormal Rhythm ECG
Junctional rhythm	Abnormal Rhythm ECG
Junctional tachycardia	Abnormal Rhythm ECG
Junctional bradycardia	Abnormal Rhythm ECG
Idioventricular rhythm	***CRITICAL TEST RESULT ***
Supraventricular rhythm	Abnormal Rhythm ECG
Supraventricular tachycardia	Abnormal Rhythm ECG
Supraventricular bradycardia	Abnormal Rhythm ECG
Uncertain irregular rhythm	Abnormal Rhythm ECG
Uncertain regular rhythm	Abnormal Rhythm ECG
With marked sinus arrhythmia	Borderline ECG
With first degree AV block (adult)	Abnormal ECG
With prolonged PR for age (pediatric)	Borderline ECG
With short pr interval	Borderline ECG
With 2nd degree AV block, Mobitz type I (Wenckebach)	***CRITICAL TEST RESULT ***
With 2nd degree AV block, 2:1 or Mobitz type II	***CRITICAL TEST RESULT ***
With occasional ventricular premature complexes	Borderline ECG
With frequent ventricular premature complexes	Abnormal Rhythm ECG
With occasional ectopic premature complexes	Borderline ECG
With frequent ectopic premature complexes	Abnormal Rhythm ECG

Conclusions – Rhythm Statements (Continued)

Statement	Conclusion
With occasional atrial premature complexes	Borderline ECG
With frequent atrial premature complexes	Abnormal Rhythm ECG
With occasional supraventricular premature complexes	Borderline ECG
With frequent supraventricular premature complexes	Abnormal Rhythm ECG
In a bigeminal pattern	Abnormal Rhythm ECG
With marked rhythm irregularity, possible non-conducted PAC, SA block, AV block, or sinus pause	***CRITICAL TEST RESULT ***
Atrial fibrillation	Abnormal Rhythm ECG
Atrial flutter/tachycardia	Abnormal Rhythm ECG
With high grade AV block	***CRITICAL TEST RESULT ***
Electronic atrial pacemaker	Abnormal Rhythm ECG
Electronic ventricular pacemaker	Abnormal Rhythm ECG
Intermittent ventricular preexcitation/WPW	***CRITICAL TEST RESULT ***

Conclusions – Contour Statements, Adult

Statement	Conclusion
Arm leads reversed	Normal ECG
Dextrocardia	Abnormal ECG
Possible right atrial enlargement	Borderline ECG
Right atrial enlargement	Abnormal ECG
Possible left atrial enlargement	Borderline ECG
Left atrial enlargement	Abnormal ECG
Ventricular preexcitation/WPW	***CRITICAL TEST RESULT ***
Borderline left axis deviation	Borderline ECG
Marked left axis deviation	Abnormal ECG
Borderline right axis deviation	Borderline ECG
Marked right axis deviation	Abnormal ECG
Indeterminate axis	Normal ECG
Low QRS voltage in extremity leads	Borderline ECG
Low QRS voltage in precordial leads	Borderline ECG
Low QRS voltage	Abnormal ECG
S1-S2-S3 pattern, consistent with pulmonary disease, RVH, or normal variant	Borderline ECG
Pattern consistent with pulmonary disease	Abnormal ECG
Possible right ventricular conduction delay	Borderline ECG
Incomplete right bundle branch block	Borderline ECG
Right bundle branch block	Abnormal ECG
Right bundle branch block and possible right ventricular	Abnormal ECG
Moderate intraventricular conduction delay	Abnormal ECG

Conclusions – Contour Statements, Adult (Continued)

Statement	Conclusion
Left anterior fascicular block	Abnormal ECG
Left posterior fascicular block	Abnormal ECG
Left bundle branch block	Abnormal ECG
Moderate intraventricular conduction delay	Borderline ECG
Intraventricular conduction delay	Abnormal ECG
Possible right ventricular hypertrophy	Abnormal ECG
Right ventricular hypertrophy	Abnormal ECG
Right ventricular hypertrophy and ST-T change	Abnormal ECG
Minimal voltage criteria for LVH, consider normal variant	Borderline ECG
Moderate voltage criteria for LVH, consider normal variant	Borderline ECG
Voltage criteria for LVH	Abnormal ECG
Possible left ventricular hypertrophy	Abnormal ECG
Left ventricular hypertrophy and ST-T change	Abnormal ECG
Any infarction, possibly acute	***ACUTE MI***
Any infarction, probably recent	***ACUTE MI***
Any infarction, of indeterminate age	Abnormal ECG
Possible infarction, probably old	Borderline ECG
Probable infarction, probably old	Abnormal ECG
Infarction, probably old	Abnormal ECG
Nonspecific ST elevation	Borderline ECG
ST elevation consistent with injury, pericarditis, or early repolarization	Abnormal ECG
ST elevation, probably early repolarization	Borderline ECG
Early repolarization	Borderline ECG
Possible acute pericarditis - exclude acute mi	***ACUTE MI***
Acute pericarditis - exclude acute mi	***ACUTE MI***
ST elevation, consider septal injury	***ACUTE MI***
Marked ST elevation, consider septal injury	***ACUTE MI***
ST elevation, consider anterior injury	***ACUTE MI***
Marked ST elevation, consider anterior injury	***ACUTE MI***
ST elevation, consider lateral injury	***ACUTE MI***
Marked ST elevation, consider lateral injury	***ACUTE MI***
ST elevation, consider inferior injury	***ACUTE MI***
Marked ST elevation, consider inferior injury	***ACUTE MI***
ST elevation, consider anterolateral injury	***ACUTE MI***
Marked ST elevation, consider anterolateral injury	***ACUTE MI***
ST elevation, consider anteroseptal injury	***ACUTE MI***
Marked ST elevation, consider anteroseptal injury	***ACUTE MI***
Junctional ST depression, consider normal variant	Borderline ECG
Marked junctional ST depression	Abnormal ECG
Minimal ST depression	Borderline ECG

Conclusions – Contour Statements, Adult (Continued)

Statement	Conclusion
Moderate ST depression	Abnormal ECG
ST depression, consider subendocardial injury	Abnormal ECG
Marked ST depression, consider subendocardial injury	***ACUTE MI***
Moderate T-wave abnormality, consider anterior ischemia	Abnormal ECG
Marked T-wave abnormality, consider anterior ischemia	Abnormal ECG
Moderate T-wave abnormality, consider lateral ischemia	Abnormal ECG
Marked T-wave abnormality, consider lateral ischemia	Abnormal ECG
Moderate T-wave abnormality, consider anterolateral ischemia	Abnormal ECG
Marked T-wave abnormality, consider anterolateral ischemia	Abnormal ECG
Moderate T-wave abnormality, consider inferior ischemia	Abnormal ECG
Marked T-wave abnormality, consider inferior ischemia	Abnormal ECG
Abnormal QRS-T angle	Abnormal ECG
Nonspecific T-wave abnormality	Borderline ECG
Nonspecific ST& T-wave abnormality	Borderline ECG
Tall T-waves, suggests hyperkalemia	Abnormal ECG
Prolonged QT interval	Abnormal ECG
Type 3 Brugada pattern (non-diagnostic)	Borderline ECG
Type 2 Brugada pattern (non-diagnostic)	Borderline ECG
Type 1 Brugada pattern, exclude recent infarction, CABG, myocarditis or drug effect	Abnormal ECG

Conclusions – Contour Statements, Pediatric

Statement	Conclusion
Arm leads reversed	Atypical ECG
Dextrocardia	Abnormal ECG
Possible right atrial enlargement	Borderline ECG
Right atrial enlargement	Abnormal ECG
Possible left atrial enlargement	Borderline ECG
Left atrial enlargement	Abnormal ECG
Ventricular preexcitation/wpw	***CRITICAL TEST RESULT***
Right axis deviation	Borderline ECG
Left axis deviation	Borderline ECG
Intraventricular conduction delay	Abnormal ECG
Right bundle branch block	Abnormal ECG
Left anterior fascicular block	Abnormal ECG
Left bundle branch block	Abnormal ECG
Possible right ventricular hypertrophy	Borderline ECG
Probable right ventricular hypertrophy	Borderline ECG

Conclusions – Contour Statements, Pediatric (Continued)

Statement	Conclusion
Right ventricular hypertrophy	Abnormal ECG
Possible left ventricular hypertrophy	Borderline ECG
Probable left ventricular hypertrophy	Abnormal ECG
Probable left ventricular hypertrophy, mild, or diastolic overload	Abnormal ECG
Left ventricular hypertrophy	Abnormal ECG
Left ventricular hypertrophy, probably mild, or diastolic overload	Abnormal ECG
Left ventricular hypertrophy, probably severe, or systolic overload	Abnormal ECG
Anterior ST elevation, consider normal variant	Normal ECG
Inferior ST elevation, consider normal variant	Borderline ECG
Anterolateral ST elevation, consider normal variant	Normal ECG
Anterolateral ST elevation, probably secondary to lvh	Borderline ECG
Anterior ST depression, consider subendocardial injury	Borderline ECG
Inferior ST depression, consider subendocardial injury	Borderline ECG
Anterolateral ST depression, consider subendocardial injury	Borderline ECG
Anterolateral ST depression, probably secondary to lvh	Borderline ECG
Minimal anterior T-wave changes	Normal ECG
Moderate anterior T-wave changes	Normal ECG
Anterior T-wave changes	Normal ECG
Marked anterior T-wave changes, consider ischemia	Borderline ECG
Marked anterior T-wave changes, consider ischemia	Borderline ECG
Consider anterior ischemia, probably secondary to rvh	Borderline ECG
Moderate inferior T-wave changes	Borderline ECG
Inferior T-wave changes	Borderline ECG
Marked inferior T-wave changes, consider ischemia	Abnormal ECG
Tall T-waves, consider normal variant	Borderline ECG
Moderate anterolateral T-wave changes	Borderline ECG
Consider anterolateral ischemia, probably secondary to lvh	Borderline ECG
Anterolateral T-wave changes, consider ischemia	Abnormal ECG
Marked anterolateral T-wave changes, consider ischemia	Abnormal ECG
Prolonged QT interval	Abnormal ECG
Consider tricuspid atresia	Abnormal ECG
Consider endocardial cushion defect	Abnormal ECG
Consider atrial septal defect, septum secundum	Abnormal ECG
Probable anterolateral infarct, consider anomalous origin of the coronary artery	Abnormal ECG
Consider Ebstein anomaly	Abnormal ECG

Critical Test Result

Some ECG findings indicate conditions that may require prompt attention from a clinician. An acute myocardial infarction is an example of such condition. Critical test results are indicated by "***" in front and behind the conclusion statement. The **VERITAS** critical conclusion statement ***ACUTE MI*** and ***CRITICAL TEST RESULT*** are defined as follows:

ACUTE MI is printed when **VERITAS** finds one of the following to be true:

- Any "acute infarction" statement
- Any "recent infarction" statement Any "acute pericarditis" statement
- Any "ST-elevation, consider injury" statement
- ""Marked ST depression, consider subendocardial injury" statement"

CRITICAL TEST RESULT is printed when **VERITAS** finds one of the following to be true:

- The Ventricular Rate is above the Critical Tachycardia limit for age
- The Ventricular Rate is below or equal to the Critical Bradycardia limit for age
- Any "Uncertain Rhythm" statement AND a Ventricular Rate of 100 bpm or more
- The "Idioventricular rhythm" statement
- Any "Second degree or high grade AV block" statement
- The "Marked rhythm irregularity" statement
- The "Prolonged QT" statement AND a QTc of 500 ms or more
- Any "Ventricular preexcitation" statement

In some clinical workflows, ECG-review by a clinician is a programmed activity and may not always be immediate. Therefore, Baxter electrocardiographs can be configured to provide a specific message on the electrocardiograph when the **VERITAS** program finds criteria for an acute myocardial infarction or other critical ECG findings, facilitating the user to alert a clinician to the finding.

22. VERITAS Resting ECG Interpretation Evaluation

Method

Introduction and General Methodology

To test the analysis program, five hundred and fifty-eight (558) 12-lead ECGs were randomly collected from adult patients in a clinical and hospital setting over a two (2) month period. These ECGs were collected and then stored in digital form. Separately, five hundred and fifty-three (553) pediatric 15-lead ECGs (standard 12 leads plus V3R, V4R and V7) were collected from various pediatric hospital settings.

In addition, consecutive 568 ECGs were added, half from a hospital digital ECG archive, half from an ambulance service, in order to increase the statistical reliability for the major rhythm categories sinus rhythm, atrial fibrillation and atrial flutter.

To test the criteria, ECGs from the data bases were submitted to a doctor to interpret as one would when reading a standard ECG available in a typical heart station. In addition, the same ECGs were interpreted by the Baxter **VERITAS** Analysis program running on a personal computer.

No reinterpretation was allowed by the doctor or the electrocardiograph.

Some categories of statements have been tested separately with different databases and methodologies, specifically pediatric ventricular hypertrophy statements and electronic pacemaker statements. The reasons and methods are explained below.

Pediatric Ventricular Hypertrophy

Left and Right Ventricular Hypertrophy (LVH and RVH) are the most common ECG interpretations in a typical pediatric cardiology population. Criteria for hypertrophy are complex, sometimes controversial, and highly age dependent. This is why the performance of the program for Left and Right Hypertrophy has been tested differently and more extensively. Approximately one thousand three hundred (1,300) 15-lead ECGs (standard 12 leads plus V3R, V4R and V7) were randomly collected in various pediatric cardiology centers.

To test the criteria, ECGs from this database were submitted to a cardiologist without automatic interpretation (blind reading) and in a standard 3x5 format at 10 mm/mV and 25 mm/s. The cardiologist was asked to divide the ECGs in 3 groups: "No RVH", "Possible RVH" and "RVH". Subsequently, the same cardiologist was represented with the ECGs but now had to divide the ECGs in "No LVH", "Possible LVH" and "LVH". In addition, the same ECGs were interpreted by the **VERITAS** Pediatric ECG Interpretation algorithm.

ECGs with a wide QRS (Right Bundle Branch Block, Left Bundle Branch Block, Ventricular Conduction Delay and Ventricular Preexcitation) were excluded from the analysis. The **VERITAS** algorithm omits the RVH and LVH calls in these cases because criteria for hypertrophy in the presence of abnormal intraventricular conduction are poorly defined.

ECGs with an erroneous order of the V-leads (for instance V7 in the V3R position) were also excluded, leading to one thousand one hundred seventy-four (1,174) included ECGs in total. Subsequently, the **VERITAS** algorithm was run again using only the standard 12 leads.

The tables below indicate the performance of the **VERITAS** program, using as “truth” both the possible and definite hypertrophy groups from the cardiologist, in confrontation with any hypertrophy call of the program. Note that the “truth” was always defined on the full 15-lead ECG.

Pacemaker Detection

The acquisition method of the aforementioned databases did not allow for adequate testing of the detection of artificial pacemaker rhythms because of the low prevalence of some pacemaker types and because of insufficient quality of the pacemaker pulse registration in the older data. Instead, sixty-nine (69) ECGs from patients with various types of pacemaker stimulation [six (6) atrial only, forty-eight (48) ventricular, fifteen (15) atrial and ventricular; about 25% also showed intrinsic rhythm] were collected from a pacemaker evaluation center. These sixty-nine (69) ECGs were used to establish the sensitivity of the **VERITAS** program (more precisely, the percentage of undetected pacemaker rhythms). A large database with circa seven thousand (7,000) ECGs from various institutions was used to measure the number of false positive pacemaker detections: all ECGs with an “Artificial Pacemaker” statement from the **VERITAS** program were reviewed by an expert. This allowed the possibility to establish the percentage of false positives. The statistical measurements (see below) were subsequently calculated on the basis of a population with 1% pacemaker ECGs.

Comparison by Categories

For purposes of determining specificity, sensitivity, and positive and negative predictive accuracy, statements have been grouped into categories. This has been done for various reasons: A higher number per category increases statistical significance; severity and probability statements (minimal, marked, possible, probable) are not well defined and highly subjective; some electrocardiographic regions (septal, anteroseptal, anterior, anterolateral and lateral) overlap and are not well defined; tachycardia, bradycardia and “normal” rate differ only in heart rate, while the algorithm that establish the statements is the same; the **VERITAS** algorithm sometimes issues a generic statement (e.g. supraventricular, uncertain) when an abnormality is detected, while the cardiologist will usually attempt to be more specific.

Some statements exist only for adult or pediatric populations and have only been tested in those populations. Some statements have very different meaning or prevalence in a pediatric or adult population and have been tested separately.

Following is a list of categories that have been used for statistical analysis, and the **VERITAS** statements that are grouped into them:

- Sinus Rhythm
 - Normal Sinus Rhythm
 - Sinus Bradycardia
 - Sinus Tachycardia
- Atrial Fibrillation
- Atrial Flutter
- Miscellaneous Rhythms
 - Ectopic Atrial Rhythm
 - Ectopic Atrial Tachycardia

- Ectopic Atrial Bradycardia
- Junctional Rhythm
- Junctional Tachycardia
- Junctional Bradycardia
- Idioventricular Rhythm
- Ventricular Tachycardia
- Supraventricular Rhythm
- Supraventricular Tachycardia
- Supraventricular Bradycardia
- Uncertain Irregular Rhythm
- Uncertain Regular Rhythm

- Supraventricular Premature Complexes
 - With Occasional Atrial Premature Complexes
 - With Frequent Atrial Premature Complexes
 - With Occasional Supraventricular Premature Complexes
 - With Frequent Supraventricular Premature Complexes

- Ventricular Premature Complexes
 - With Occasional Ventricular Premature Complexes
 - With Frequent Ventricular Premature Complexes
 - With Occasional Ectopic Premature Complexes
 - With Frequent Ectopic Premature Complexes

- Atrial Electronic Pacemaker

- Ventricular Electronic Pacemaker

- High degree AV-block
 - With second degree AV-block type Mobitz 1 (Wenckebach)
 - With second degree AV-block type Mobitz 2
 - With high degree AV-block

- Prolonged PR-Interval (First Degree AV-block)

- Short PR-interval (adult only)

- Right Atrial Enlargement
 - Possible Right Atrial Enlargement
 - Right Atrial Enlargement

- Left Atrial Enlargement
 - Possible Left Atrial Enlargement
 - Left Atrial Enlargement

- Right Axis Deviation
 - Borderline Right Axis Deviation
 - Marked Right Axis Deviation
- Left Axis Deviation
 - Borderline Left Axis Deviation
 - Marked Left Axis Deviation
- Low QRS Voltage (adult only)
 - Low QRS Voltage In Extremity Leads
 - Low QRS Voltage In Precordial Leads
 - Low QRS Voltage
 - S1-S2-S3 Pattern, Consistent With Pulmonary Disease, RVH, Or Normal Variant
 - Pattern Consistent With Pulmonary Disease
- Right Bundle Conduction Right
 - Bundle Branch Block
 - Right Bundle Branch Block, plus possible right ventricular hypertrophy

Note: Moderate right conduction delays have not been considered.

- Nonspecific intraventricular conduction block

Note: Moderate conduction delays have not been considered.

- Left bundle branch block

Note: Moderate left conduction delay and fascicular block have not been considered.

- Right Ventricular Hypertrophy
 - Possible Right Ventricular Hypertrophy
 - Probable Right Ventricular Hypertrophy
 - Right Ventricular Hypertrophy
 - Right Ventricular Hypertrophy and ST-T Change
- Left Ventricular Hypertrophy
 - Minimal Voltage Criteria For LVH, Consider Normal Variant
 - Moderate Voltage Criteria For LVH, Consider Normal Variant
 - Voltage Criteria For LVH
 - Possible Left Ventricular Hypertrophy
 - Probable Left Ventricular Hypertrophy
 - Left Ventricular Hypertrophy And S-T Change

Note: Separate tables are compiled for Ventricular Hypertrophy for Adults, Pediatric 12-lead ECGs and Pediatric 15-lead ECGs.

- Inferior Infarction (adult only)
 - All inferior infarction statements

- Anterior Infarction (adult only)
 - All septal, anterior, lateral, anteroseptal and anterolateral infarction statements
- ST-T changes - adult
 - All adult ST-depression and T-wave abnormality statements
- ST-T changes - pediatric
 - All pediatric ST-depression and T-wave abnormality statements
- Prolonged QT
- Consider Endocardial Cushion Effect (pediatric only)

Results

Results are presented in two different forms. In order to more clearly view the positive and negative calls by the physician and the Baxter **VERITAS** Analysis Program, the following tables present data in a 2 x 2 truth matrix format (Table 1 and 2). Summary statistical measurements such as sensitivity and specificity are given below (Table 3 and 4). For this presentation, the categories have been divided in two groups: rhythm statements and statements based on waveform morphology.

Definitions

In the matrix format shown, the Physician Statement is used as the gold standard against which the Baxter **VERITAS** ECG Analysis Program is compared.

		Baxter VERITAS Analysis Program	
		+	-
Physician Statement	+	True Positive	False Negative
	-	False Positive	True Negative

Specific definitions for each of the terms used above are as follows:

True Positive (TP)	A true positive is called when the analysis program (TP) agrees with the positive diagnostic statement made by the physician, i.e., true positive call by the analysis program.
True Negative (TN)	A true negative is called when the analysis program (TN) agrees with the negative diagnostic statement made by the physician, i.e., the condition under question is not called by either the analysis program or the physician.

False Positive (FP)	A false positive occurs when the analysis program (FP) appends the diagnostic statement to the ECG in question whereas the physician indicates that the condition did not exist, i.e., a false positive call by the analysis program.
False Negative (FN)	A false negative occurs when the physician appends the (FN) diagnostic statement to the ECG in question whereas the analysis program indicates that the condition did not exist, i.e., a false negative call by the analysis program.

In summary, True Positive and True Negatives are correct diagnostic statements made by the analysis program since they truly reflect the positive and negative calls made by the physician. False Positives and False Negatives occur when the analysis program calls do not agree with the physician statement. A False Positive, in effect, overcalls a particular diagnostic statement whereas a False Negative undercalls. The prevalence of the condition in the databases used can be determined by summing the True Positive and False Negative numbers.

In addition, the values for sensitivity, specificity and predictive accuracy are presented in table form following the analysis matrices. True Positives, True Negatives, False Positives and False Negatives have been used to calculate the Sensitivity, Specificity and the Predictive Accuracy.

Formulas used for calculating the above values are:

$$\text{Sensitivity} = \frac{\text{TP}}{\text{TP} + \text{FN}} \quad \text{Specificity} = \frac{\text{TN}}{\text{TN} + \text{FP}}$$

$$\text{Positive Predictive Accuracy} = \frac{\text{TP}}{\text{TP} + \text{FP}}$$

$$\text{Negative Predictive Accuracy} = \frac{\text{TN}}{\text{TN} + \text{FN}}$$

Table 1, Rhythm Criteria Truth Matrices

Sinus Rhythm			Atrial Fibrillation			Atrial Flutter		
	+	-		+	-		+	-
+	1471	43	+	100	9	+	14	3
-	7	158	-	15	1555	-	10	1652

Miscellaneous Rhythms			High Degree AV Block			Ventricular Preexcitation		
	+	-		+	-		+	-
+	16	2	+	5	2	+	6	9
-	19	1064	-	0	1101	-	0	1096

Table 1, Rhythm Criteria Truth Matrices (continued)

Premature Ventricular Complexes		Supraventricular Premature Complexes	
+	-	+	-
59	2	24	10
13	1037	4	1073

Atrial Electronic Pacemaker		Ventricular Electronic Pacemaker	
+	-	+	-
0.81 %	0.19 %	0.98 %	0.02 %
0.11 %	98.89 %	0.04 %	98.96 %

Table 2, Contour Criteria Truth Matrices

Prolonged PR-Interval			Short PR-Interval (adult only)			Right Atrial Enlargement		
	+	-		+	-		+	-
+	61	11	+	16	2	+	18	13
-	9	1030	-	6	534	-	0	1080
Left Atrial Enlargement			Right Axis			Left Axis		
	+	-		+	-		+	-
+	55	13	+	31	3	+	86	9
-	9	1034	-	5	1072	-	6	1010
Low QRS Voltage (adult only)			Right Bundle Conduction			Nonspecific Conduction Abnormality		
	+	-		+	-		+	-
+	8	6	+	53	5	+	11	2
-	3	541	-	6	1047	-	12	1086

Table 2, Contour Criteria Truth Matrices (continued)

Left Bundle Conduction		Right Ventricular Hypertrophy (adult only)		Left Ventricular Hypertrophy (adult only)	
	+	-		+	-
+	13	1	+	4	6
-	3	1094	-	1	547

Right Ventricular Hypertrophy (pediatric 12 lead)		Left Ventricular Hypertrophy (pediatric 12 lead)		Right Ventricular Hypertrophy (pediatric 15 lead)	
	+	-		+	-
+	113	59	+	126	29
-	52	950	-	51	968

Left Ventricular Hypertrophy (pediatric 15 lead)		
	+	-
+	127	28
-	51	968

Table 2, Contour Criteria Truth Matrices (continued)

Anterior Infarction (adult only)			Inferior infarction (adult only)			ST-T Changes Adult		
	+	-		+	-		+	-
+	52	20	+	68	13	+	132	22
-	1	485	-	3	474	-	38	366

ST-T Changes Pediatric			Prolonged QT			Endocardial Cushion Effect (pediatric)		
	+	-		+	-		+	-
+	18	3	+	18	2	+	6	1
-	4	528	-	2	1089	-	6	540

Table 3, Sensitivity, Specificity and Predictive Accuracies, Rhythm Criteria

RHYTHM CRITERIA				
DIAGNOSTIC STATEMENT	SENSITIVITY	SPECIFICITY	POS PREDICTIVE ACCURACY	NEG PREDICTIVE ACCURACY
Sinus Rhythm	97.2	95.8	99.5	78.6
Atrial Fibrillation	91.7	99.0	87.0	99.4
Atrial Flutter	82.4	99.4	58.3	99.8
Miscellaneous Rhythms	92.9	98.2	57.8	99.8
High degree AV-block	71.4	100	100	99.8
Ventricular preexcitation	42.9	100	100	99.2
Ventricular Premature Complexes	96.7	98.8	81.9	99.8
Supraventricular Premature Complexes	70.6	99.6	85.7	99.1
Atrial Electronic Pacemaker	81.0	99.9	88.0	99.8
Ventricular Electronic Pacemaker	98.0	100	96.1	100

Table 4, Sensitivity, Specificity and Predictive Accuracies, Contour Criteria

CONTOUR CRITERIA				
DIAGNOSTIC STATEMENT	SENSITIVITY	SPECIFICITY	POS PREDICTIVE ACCURACY	NEG PREDICTIVE ACCURACY
Prolonged PR-Interval	84.7	99.1	87.1	98.9
Short PR-interval (adult)	88.9	98.9	72.7	99.6
Right Atrial Enlargement	58.1	100	100	98.8
Left Atrial Enlargement	80.9	99.1	85.9	98.8
Right Axis	91.1	99.5	86.1	99.7
Left Axis	90.5	99.4	93.5	99.1
Low QRS Voltage (adult)	57.1	99.4	72.7	98.9
Right Bundle Conduction	91.4	99.4	89.8	99.5
Nonspecific Conduction Abnormality	84.6	98.9	47.8	99.8
Left Bundle Conduction	92.9	99.7	81.3	99.9
Right Ventricular Hypertrophy, adult	40.0	99.8	80.0	98.9
Left Ventricular Hypertrophy, adult	96.9	97.7	92.5	99.1
Right Ventricular Hypertrophy, pediatric 12-lead	65.7	94.8	68.5	94.2
Left Ventricular Hypertrophy, pediatric 12-lead	81.3	95.0	71.2	97.1
Right Ventricular Hypertrophy, pediatric 15-lead	79.7	92.6	64.9	96.4
Left Ventricular Hypertrophy, pediatric 15-lead	81.9	95.0	71.3	97.2
Inferior Infarction	84.0	99.4	95.8	97.3
Anterior Infarction	72.2	99.8	98.1	96.0
ST-T Changes, adult	85.7	90.6	77.6	94.3
ST-T Changes, pediatric	85.7	99.2	81.8	99.4
Prolonged QT	90.0	99.8	90.0	99.8
Endocardial Cushion Effect (pediatric)	85.7	98.9	50.0	99.8

Prevalence of Conclusion Statements

The prevalence of the VERITAS “Conclusion” statements, including the Critical Test Result statements has been measured using a database consisting of 8000 consecutive ECG’s taken by an emergency (ambulance) service plus 27500 ECG’s in four groups of consecutive ECG’s from different teaching hospitals from various countries. Given the source of these ECG’s, a high prevalence of abnormality can be expected. As can be seen in the table below, in this population one in 20 ECG’s have a critical annotation.

Conclusion	Prevalence %
Normal ECG	18.3
Borderline ECG	21.4
Abnormal Rhythm ECG	11.1
Abnormal ECG	44.1
CRITICAL TEST RESULT	2.1
Acute MI	3.0

Interval Measurements

The global PR-interval, QRS-duration and QT-interval are measured using the “median beat”, using all available leads. The first and last wave of the QRS for individual leads start and end with the global onset and offset of the QRS, therefore iso-electric segments before the Q-wave and after the S-wave may be included in the Q or S duration measurements of the program.

The interval measurements have been tested according to IEC 60601-2-51 (2003) on 100 ECG's with established “truth”. A positive difference means that the **VERITAS** measurement is bigger than the declared truth.

Table 5, Accuracy of Interval Measurements

Dimensions in ms

Global measurement	Acceptable mean difference	Measured mean difference	Acceptable standard deviation	Measured standard deviation
PQ-interval	± 10	2.1	10	7.2
QRS-duration	± 10	-0.4	10	5.9
QT-interval	± 25	-7.8	30	10.6

The stability of the measurements in conditions of noise has been measured according to IEC 60601-2-51 (2003), by adding high frequency, line frequency and base-line artifact and comparing the results with the measurements on the same ECG's without noise. Results were as follows:

Table 6, Stability of Interval Measurements Against Noise

Global measurement	Type of added noise	Disclosed differences	
		Mean ms	Standard deviation ms
P-duration	High frequency	1.50	3.21
P-duration	Line frequency	0.63	2.00
P-duration	Base-line	0.13	1.46
QRS-duration	High frequency	-0.38	1.51
QRS-duration	Line frequency	0.13	0.99
QRS-duration	Base-line	-0.25	1.28
QT-interval	High frequency	0.25	1.58
QT-interval	Line frequency	0.13	1.55
QT-interval	Base-line	-0.13	0.99

23. Electrode Reversal Algorithm

Electrode Reversal Algorithm

Electrode reversals are a problem in electrocardiography. Literature reports that between 0.4 and 4 % of ECG's to be taken with reversed electrodes. The Baxter electrocardiographs include an algorithm that detects electrode reversals in real time before the 10 second ECG is captured and analyzed. The device provides a warning to the ECG technician to check the lead wire attachments when a reversal is suspected. This method prevents ECG's with reversed electrodes to be collected and analyzed. Electrode reversals cannot be determined with 100% precision, because their effect may be small or may look like a possible real ECG pattern, so there will always be some false indications, and some real reversals missed. The **VERITAS** method has been designed to in particular to have a very high specificity, meaning a low false indication rate, because we think that a high false rate will cause the ECG technician to ignore the reversal message eventually. That means that some real reversals will be missed, but the program still detects most of the reversals, and so helps improve the quality of ECG taking.

Some electrode reversals have the same effect on the ECG as certain pathologies, like an old infarction or an axis shift, and cannot be determined with sufficient certainty. Those reversals cannot be detected with a low enough false indication rate to be useful. An example is the reversal of the Right Arm and Left Leg, a diagonal reversal. It turned out that, even with a 50% miss rate, 30% of all the false indications were RA-LL reversals. ECG technician almost never make this mistake: we measured in one institution that less than one in every 5000 ECG's, RA and LL were switched. So we decided not to try to detect RA-LL reversals: little help for a lot of false indications. The same for the other diagonal reversal, Left Arm and Right Leg.

Some electrode reversals have almost NO effect on the ECG, they are basically harmless. This is the case with the Left Leg – Right Leg reversal. This reversal is not detectable, obviously.

For chest leads, the **VERITAS** program only attempts to detect reversal of neighbors, like V2-V3, V5-V6, because they are the most frequent and most difficult to detect. Any other reversal (like V2 with V5) will likely be reported as any of V1-V2, V2-V3, V4-V5 or V5-V6, which serves the purpose of indicating one of the involved electrodes. The ECG technician will find the other one, obviously.

Similarly, reversals between Limb lead and Chest leads are not specifically detected, but may appear as either Limb lead or Chest lead reversal messages.

Pacemaker ECG's are very different from other ECG's. The QRS-morphology is very abnormal for ventricular pacing and the P-wave is very different for atrial pacing, and depend much on the pacemaker lead location. The performance of an electrode reversal algorithm is not good for pacemaker ECG's. We decided to deactivate the reversal algorithm when pacemaker spikes are detected by the electrocardiograph, just to avoid false reversal messages.

The **VERITAS** lead reversal algorithm efficacy has been tested with a database with a large number of ECG's. The database consisted of 18000 ECG's from a large teaching hospital, for which two previous ECG's were also available. The **VERITAS** algorithm was run on this database, and previous ECG's were used to certify any existing electrode reversals in the database and to find false positives. The existing true reversals were removed, and a real reversal was simulated by switching or inverting the ECG leads in the file appropriately. The **VERITAS** program was now run again, and it was measured how many of these simulated reversals were captured. In this way the sensitivity could be measured for all reversals except the ones that involved the Right Leg electrode. The RL electrode is not part of any lead, so a switch cannot be simulated with existing data. The sensitivity of RL switches was measured with a number of real subjects, company employees, presumably healthy.

The results of this evaluation are reported in the table below¹. Ar-Lg is the vertical reversal of limb electrodes; horizontal reversal has the same effect as RA-LA reversal.

(%)	RA-LA	LA-LL	RA-RL	Ar-Lg	V1-V2	V2-V3	V3-V4	V4-V5	V5-V6	All
Sensitivity	90.91	22.44	70	70	74.56	82.70	97.67	97.25	91.28	79.40
Specificity	99.91	99.78	100	100	99.90	99.82	99.65	99.85	99.88	98.61
Prevalence	0.16	0.22	0.04	0.01	0.07	0.32	0.09	0.21	0.48	0.61

As can be deducted from the table, the **VERITAS** electrode reversal algorithm reduced the ECG's taken with reversals by almost 80%, at the price of a false indication rate of only 1.4%, that is one ECG every 70. In this hospital, the number of reversals was reduced from one every 60 to one every 300 ECG's.

¹ From published article: The development and validation of an early warning system to prevent the acquisition of 12-lead resting ECG's with interchanged electrode positions. Johan de Bie, PhD, David W. Welch Allyn, PhD, Todd F. Clark. Journal of Electrocardiology 47 (2014) 794-797.

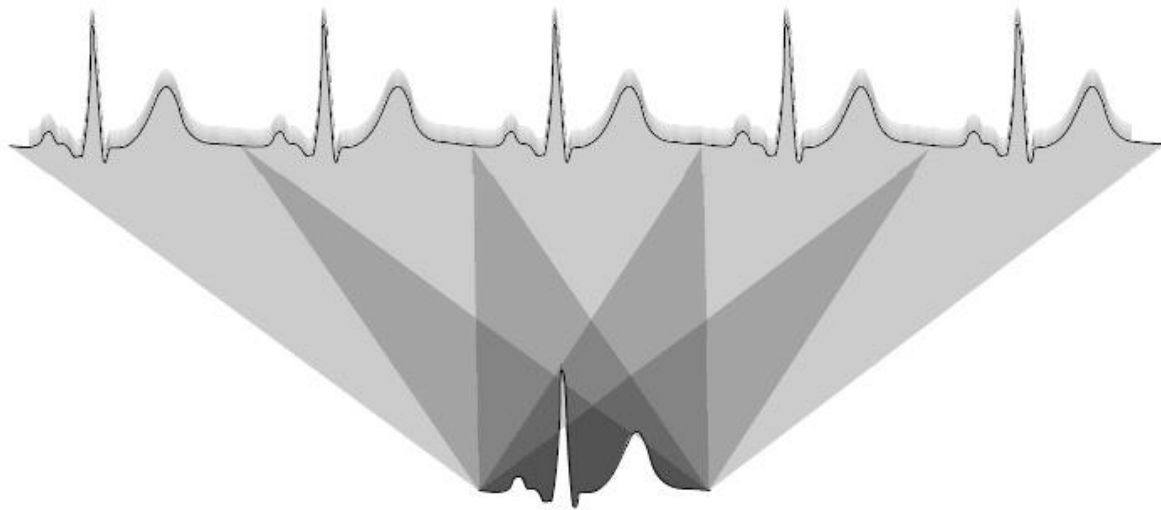
24. Signal Averaging Algorithm

Signal Averaging Algorithm

Signal Averaging is a method to record a representative beat with an extremely low level of noise and a high frequency resolution. The method allows the analysis of very small high frequency signals that are present in the ECG signal, which are normally not detectable on a beat-to-beat basis. The main application of signal averaging is the measurement of so-called “Late Potentials” in the QRS complex. Late Potentials are low amplitude, high frequency signals that can be measured at the end of the QRS complex. Their presence is believed to be an indication of slow and fragmented conduction of the depolarization wave front at the borders of infarcted necrotic areas. They are an indication of a viable substrate for re-entry and a risk factor for ventricular arrhythmias like ventricular tachycardia, in particular for post-infarct patients. See for a review of the background and indication for signal averaging and late potentials the joint statement from the European Society of Cardiology, the American Heart Association and the American College of Cardiology.¹

Traditionally, for the evaluation of late potentials, three orthogonal bipolar leads have been used. See the electrocardiograph's user manual for electrode positions and the mapping of the leads to the normal 10-wire patient cable labeling. The **VERITAS** signal averaging algorithm uses the electrocardiograph's signal as it is sampled at 1000 samples per second and an amplitude resolution of circa 1 μ V, after it is filtered for low frequency baseline movements. It compares each beat as it is acquired with the current average. Beats are then aligned with the average by shifting the new beat forward and backward in increments of one ms until the best correlation is found. If the maximum correlation is less than 90% in a 150 ms centered around the QRS, the beat is ignored. Once the alignment has finished and the new beat accepted, it is then added to the average, sample by sample. This concept is schematically illustrated in the figure below.

¹ From: “Standards for analysis of ventricular late potentials using high- resolution or signal-averaged electrocardiography. A statement by a Task Force Committee of the European Society of Cardiology, the American Heart Association, and the American College of Cardiology”. G Breithardt, ME Cain, N el-Sherif, NC Flowers, V Hombach, M Janse, MB Simson and G Steinbeck. Circulation 1991;83:1481-1488



The procedure is similar to the formation of the median beat in the resting ECG measurement program (see page 7 of this guide), but with a higher resolution, and a higher correlation requirement for inclusion.

The averaging procedure reduces the uncorrelated noise in the original signal with the square root of the number of beats averaged. For example, if the noise in the original signals has an amplitude of $20\text{ }\mu\text{V}$, after averaging 25 beats, it will be reduced by a factor of 5 (square root of 25), therefore to $4\text{ }\mu\text{V}$.

Note that the “mains” or AC notch filter is turned off during the signal averaging procedure. Notch filters have the characteristic of producing a small amount of “ringing”, a short high frequency oscillation whenever an impulse is encountered, that may have the appearance of late potentials.

The average beat is now filtered to leave only the high frequency components characteristic of late potentials. The filter used is bidirectional and derived from a four-pole Butterworth filter with an attenuation of 24 dB/octave. The corner frequency can be set by the user; common frequencies are 25 or 40 Hz. The filtered X, Y and Z leads are now combined into a single vector

magnitude ($\sqrt{X^2 + Y^2 + Z^2}$), and displayed. This is the signal on which the late potentials are measured.

The root mean square noise amplitude remaining on a 40 ms segment of the ST segment of the filtered vector magnitude is measured by the program after every beat. The user can program the device to stop averaging when a maximum number of beats has been reached, or a minimum amount of noise, or both. It is recommended to choose a noise level of $1\text{ }\mu\text{V}$ or less and not more than 300 beats.

The next step of the analysis is the measurement of the end of the filtered vector magnitude QRS complex. This point is defined as the midpoint of the last 5 ms segment in which the mean voltage exceeds the mean noise level plus three times the standard deviation of the noise. The beginning of the complex is measured in the traditional way from the unfiltered QRS.

The program also measures the root mean square voltage of the last 40 ms of the filtered QRS and the amount of time that the root mean square voltage remains below 40 μV . The **VERITAS** signal averaging program reports these values, but does not provide a conclusion whether or not late potentials exist. Common criteria used with a filter corner frequency of 25 Hz are that late potentials exist when:

- 1) The filtered QRS is longer than 114 ms; and
- 2) There is less than 20 μV of signal in the last 40 ms of the vector magnitude complex; and
- 3) The terminal vector magnitude complex remains below 40 μV for more than 38 ms.

Note that these criteria are not universal and are dependent on filter frequency and on the leads and electrode positions used. The **VERITAS** program is able to repeat the measurements with different filters without re-acquiring the signal.

The **VERITAS** signal averaging algorithm has been measured to accurately reproduce artificial late potentials on real ECG signals within a duration precision of 5 ms and with an amplitude precision of 3 μV .