Hewlett-Packard Interpretive Cardiograph

Physician's Guide

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About This Guide

This guide explains how the clinical ECG reports are analyzed by an Hewlett-Packard interpretive cardiograph. It also shows how an HP interpretive cardiograph ensures reliable results.

Note

Computerized ECG analysis should always be reviewed by a qualified physician.

Who Should Read This Guide?

This guide is intended for physicians who read or review ECGs produced by a Hewlett-Packard interpretive cardiograph. It also may be of interest to other healthcare professionals who want to know more about HP's interpretive cardiographs. The following table shows where you can find additional information on related topics.

Information	Resource
How to configure the cardiograph.	The *User's Reference Guide* provided with your cardiograph.
Description of ECL (the programming language in which the interpretive criteria is written).	*ECL Programmers Reference Manual.* Order from Hewlett-Packard
Complete ECL program listing of all criteria statements.	*Interpretive Criteria Listing.* Order from Hewlett-Packard
Operating instructions and guidelines for the Hewlett-Packard ECG Management System.	ECG Management System manuals, or contact your Hewlett-Packard customer support representative.

Note

This book discusses several functions that may not be available on your HP interpretive cardiograph, such as floppy-disk storage, modem data transmission, extended measurement report, signal averaged ECG, internal configurations, alternate patient lead sets or patient lead configurations. Refer to the *User's Guide* supplied with your cardiograph for a guide to the functions available on your cardiograph.

Documentation Map

Documentation Map

If you want to:	Use this manual:
Verify that all equipment is included	*Packing List*
Record ECGs	*Operating Guide*
Enter patient ID	
Make copies of ECGs	
Store ECGs[1]	
Transmit or receive ECGs[1]	
Troubleshoot problems	
Maintain the cardiograph	
Set up the cardiograph	
Install battery	
Install software[1]	
Load paper	
Configure the cardiograph	*User's Reference Guide*
Prepare patient	
Maintain the cardiograph	
Install and use the modem[1]	
Order supplies	
Use filters	
Understand analysis	*Physician's Guide*

1 Note: your cardiograph may not be equipped for this function.

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1

Why Use an Interpretive Cardiograph?

While a computer-interpreted ECG report is not a substitute for overreading by a qualified physician, computerized interpretation is a very useful tool in improving physician and staff productivity. The program's basic measurements and interpretation can help the physician save time when overreading reports.

The HP ECG Analysis program is highly effective at screening normal ECGs. ECGs requiring comment already have the initial computerized commentary on them, so the physician has a head start on the final interpretation.

The HP ECG Analysis Program makes quick and consistent measurements of the ECG. It makes detailed measurements over the entire ECG, providing more data for a more accurate interpretation. The program can help identify problem areas for the physician. This saves time for the physician or editing technician who may only need to add, delete or modify a few statements.

Those who read ECGs infrequently may find the interpreted reports to be useful training tools. They can refer to reasons associated with each statement for the rationale for why a particular condition was suggested.

What You Can Expect of the HP ECG Analysis Program

The HP ECG Analysis Program provides an analysis of the amplitudes, durations and morphologies of the ECG waveform. The ECG waveform analysis is based upon standards of interpretation of these parameters as well as upon calculations of the electrical axis and relationship between leads.

Just as cardiologists may disagree on interpretations, occasionally there is some disagreement between an interpretation given by the computer program and that made by a cardiologist. The interpreted ECG is a tool to assist the physician in making a clinical diagnosis. It is best used in conjunction with the physician's knowledge of the patient, the results of the physical examination, the ECG tracing, and other findings.

2

How Computerized ECG Interpretation has Developed

Development of computer-assisted ECG analysis began in the 1960s. Initially only used in research facilities, computer interpretation has developed into an accepted tool for physicians.

Hewlett-Packard entered the computerized ECG analysis field in 1968 when it obtained and offered several existing analysis programs. In 1975 Hewlett-Packard introduced one of the first commercially available systems to provide long-term ECG storage. ECGs were stored, retrieved and managed on this first HP 5600C ECG Management system. The system analyzed ECGs using the existing analysis programs. Hewlett-Packard was able to identify some unique contributions it could make to the field of ECG analysis, which resulted in the 1978 introduction of the ECG Criteria Language (ECL). ECL enabled HP to write the Hewlett-Packard Adult Criteria program, which replaced all of the earlier programs.

In 1980 Hewlett-Packard introduced the HP 4700 PageWriter cardiograph, which digitally acquired ECGs. In 1983 it became possible to transmit ECGs digitally over phone lines to the HP 5600C ECG Management system.

Computerized ECG interpretation became available on the cardiograph in 1983 when Hewlett-Packard introduced the HP 4760AI PageWriter Intelligent cardiograph. The proven ECG analysis program from the HP 5600C was implemented on the HP 4760AI cardiograph. Hewlett-Packard's Pediatric Criteria program was also introduced in 1983 for both the HP ECG Management system and the cardiograph.

Your HP interpretive cardiograph continues the tradition of improving the performance of the analysis program. The ECG Measurement program has been enhanced and is now in its seventh revision. Simultaneous twelve-lead acquisition allows detection of waveform onsets and offsets more accurately. The additional waveform information helps to define each beat's components better in the measurements section of the analysis. This increased definition produces more consistent results overall.

The Criteria program continues to evolve. Since its initial release, the program has undergone several changes. The current release is the eighth revision of the Adult analysis criteria and the fourth revision of the Pediatric analysis criteria. Suggestions made by an advisory group of respected electrocardiographers are evaluated regularly for inclusion in subsequent releases.

3

Understanding Simultaneous 12-Lead Acquisition

Computer-assisted ECG analysis begins with acquiring high quality, accurate ECG waveforms. Your HP interpretive cardiograph simultaneously acquires up to 16 ECG leads (depending on the model) and analyzes 12 leads. Although the printed recording doesn't show it, the Hewlett-Packard ECG Analysis Program uses the full ten second recording in each lead. Figure 3-1 shows how the Auto 3x4 format displays consecutive 2.5 second segments of 12 leads, three leads at a time. Figure 3-2 shows how the Auto 6x2 format displays consecutive 5 second segments of 12 leads, six leads at a time.

Figure TLD34 here.

Figure 3-1. Ten Seconds of 12 Leads on an Auto 3x4 Report.

Figure TLD62 here.

Figure 3-2. Ten Seconds of 12 Leads on an Auto 6x2 Report.

Besides the conventional 12 leads, your cardiograph may have the capability to use one of the following sets of supplemental leads:

pediatric leads	V4R, V3R, V7
or Frank leads	X, Y, Z
or research leads	VX1, VX2, VX3, VX4

The pediatric leads may be used for confirming certain right-sided interpretations in pediatric and, occasionally, in adult applications. The research leads provide four additional V-type leads that may be placed at your discretion and recorded simultaneously with the standard 12 leads. Because their location is not preassigned as with the pediatric leads, they are simply labeled VX1 through VX4. The Frank leads, X, Y, and Z,

capture a three-dimensional, orthogonal view of the heart's electrical activity. If they are available on your cardiograph, any of these supplemental leads can be displayed as rhythm strips with the conventional 12-lead ECG. Regardless of which supplemental set of leads you choose, all ECG waveforms are acquired simultaneously.

Digitizing the ECG

The continuous, analog ECG signal at the body surface is digitized at the input to the cardiograph. On some cardiographs the signals are digitized internally, on others, they are digitized by the patient module (as shown in Figure 3-3). The ECG waveform data is captured at a sample rate that significantly exceeds the 250 samples per second at 5 μV resolution requirements of the Hewlett-Packard Analysis Program. It is also fast enough to accurately detect pacemaker pulses.

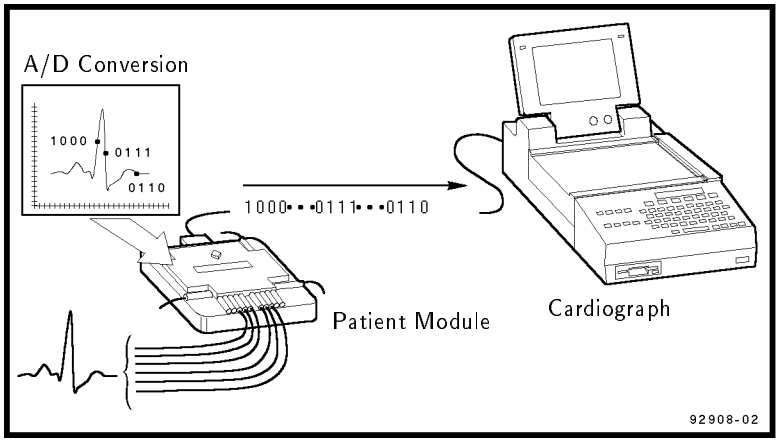

Figure 3-3. Digitizing the ECG.

As the ECG is converted to digital form, it is digitally filtered. Not only is this approach more flexible, it provides superior results when compared to analog filtering. The HP cardiograph's digital signal processing ensures the most accurate reproduction of the patient's ECG waveforms.

The American Heart Association's 1989 *Recommendations for standardization and specifications in automated electrocardiography: bandwidth and digital signal processing*, extended the recommended bandwidth for adult ECGs to 125 Hz and for infant ECGs to 150 Hz. These recommendations are met by the data acquisition scheme in all HP interpretive cardiographs.

The HP interpretive cardiograph's input circuitry has a dynamic range that meets or exceeds current AAMI standards.

Reducing Artifact

Electrical interference, patient respiration, patient movement and muscle tremors can add noise and artifact to the ECG signal. Poor quality electrodes or inadequate patient preparation can also degrade the ECG signal. Your HP interpretive cardiograph has been carefully designed to substantially reduce artifact and accurately record the ECG signal.

Common Mode Rejection

Some of the noise sources that interfere with the ECG signal are common to each electrode attached to the patient. To the extent that they have an identical effect on the ECG signal in each lead, they are removed from the ECG by the cardiograph's input circuitry as the signal is acquired and digitized. The amount of reduction of these *common mode* signals is referred to as the common mode rejection ratio. The common mode rejection ratio of your HP interpretive cardiograph's input circuitry meets or exceeds current AAMI standards.

The effects of AC interference on the ECG are twofold, common mode and differential mode. The interference which is common to all electrodes (common mode) is removed in the HP interpretive cardiograph's input circuitry. Even though this circuitry greatly reduces common mode noise, good ECG technique is still important. In the case of differential mode, the magnetic fields associated with electrical power interact with the lead wires. This induces electrical signals which appear as high frequency noise on the ECG. How much distortion there is depends on the size of the loop created by the lead wire and its orientation. A good way to prevent this distortion is to align the lead wires with the patient's body.

Using Filters

Computerized signal processing in the HP interpretive cardiograph removes noise and artifact while minimizing distortion of the ECG waveform. A sophisticated set of digital filters can be selected by the operator (or during configuration) to optimize the ECG waveform. Digital filters have the advantage over traditional analog filters in their ability to be finely tuned to selected frequencies. Unlike analog filters, digital filters are very stable over time and temperature, meaning that ECGs taken under various conditions will receive the same high quality filtering.

With the exception of the AC filter, which is very selective, there is always some tradeoff in filtering between fidelity and clarity of the ECG trace. The more filtering applied to the signal, the greater the possibility of removing details of the ECG signal with noise of the same frequency.

There are a variety of noise sources which can potentially degrade the reproduction of the ECG signal. Several types of filters can be used in your HP interpretive cardiograph to counteract them and reduce the artifact in the ECG. In the lower right-hand corner of the HP interpretive ECG report is a box containing information about the filtering options used on each ECG. Note that your PageWriter may or may not have all of these filters.

Insert artwork here.

Figure 3-4. The Filter Box on the ECG Report.

Frequency Response Filters

These filters suppress frequencies at the high and low ends of the ECG signal spectrum. The available high frequency response filter settings are 40, 100 and 150 Hz. In 1989, the American Heart Association recommended that frequencies up to 125 Hz be recorded for adult ECGs and that frequencies up to 150 Hz be recorded for pediatric ECGs (American Heart Association's 1989 *Recommendations for standardization and specifications in automated electrocardiography: bandwidth and digital signal processing*). Your HP interpretive cardiograph records and analyzes all ECGs with frequencies up to 150 Hz. The 40 and 100 Hz filters only affect the printed report. They result in a smoother-looking ECG waveform, at the expense of eliminating some of the fine detail in the signal. Small deflections, notches, and slurs may be distorted or may disappear altogether if one of these filters is selected for the Auto frequency response.

The available low frequency response filter settings are 0.05, 0.15, and 0.5 Hz. The 0.5 Hz filter is also the baseline wander filter. The low frequency response filter settings affect analyzed and printed ECGs.

The frequency response of the ECG is indicated in the ECG report's filter box.

AC Filter

The AC filter adaptively detects the AC interference in the ECG signal and very selectively removes it without affecting the ECG. This filter affects analyzed and printed ECGs.

The AC filter removes interference created by the magnetic fields associated with electrical power interacting with the lead wires. The frequency of the AC interference is very stable at 60 or 50 Hz, so the AC filter can remove the AC noise and leave the ECG signal intact.

The line power, or AC, filter is indicated in the second position of the ECG report filter box by the symbol "∿ " (your cardiograph may also report the configured line frequency 50 or 60). If the filter box does not contain this symbol, the AC filter was not used for the ECG.

Baseline Wander Filter

Baseline wander is the term used to describe the slow (typically 0.1–0.2 Hz) drifting of the ECG baseline up or down during the ECG recording. Baseline wander may result from patient respiration or from other sources. Severe baseline wander can make it difficult to determine the true wave shapes in the ECG.

Early analog attempts to suppress the effects of baseline wander resulted in "smearing" the QRS complex into the ST segment. In 1975, the American Heart Association addressed this problem by recommending that frequencies as low as 0.05 Hz be preserved in the ECG signal to prevent the then common ST segment distortion. (American Heart Association's 1975 *Recommendations for standardization of leads and of specifications for instruments in electrocardiography and vectorcardiography.*)

Since the advent of digital ECG acquisition in the 1980's, effective baseline wander suppression techniques that do not distort the ST segment have been a part of Hewlett-Packard's cardiographs. While the lower frequency limit of 0.15 Hz, which we recommend for normal use, eliminates baseline wander from most ECGs, you may occasionally need extra suppression. The Filter key on the key panel can be configured to allow the operator to turn on the baseline wander filter when needed. The baseline wander filter suppresses frequencies below 0.5 Hz. It affects analyzed and printed ECGs.

The baseline wander filter is represented by a "W" in the ECG report's filter box.

Note

Because of the continuous recording of the ECG in Manual mode, a different 0.5 Hz (baseline wander) filter that may distort the ST segment must be used. Therefore, do not attempt to interpret the contour aspects of Manual ECGs at this setting. If contour analysis is important in Manual mode, use the 0.05 Hz Manual frequency response setting which minimizes the ST segment distortion. Regardless of the low frequency setting in Manual mode, the rhythm characteristics of the ECG are accurately recorded.

Artifact Filter

The Artifact filter removes skeletal muscle artifact. This source of noise is the most difficult to eliminate because it has the same frequencies as the ECG signals. The Artifact filter, while eliminating skeletal muscle artifact, also removes low amplitude, high frequency components from the ECG.

Specifically, the filter removes up to 50 μV of signals in the frequency range from 5 Hz to 150 Hz which can affect P waves as well as the entire QRS-T complex. Use the Artifact filter only as a last resort for ECGs which would otherwise be unreadable due to significant levels of muscle artifact. The Artifact filter only affects ECG data on the printed ECG report and not ECG data that is analyzed.

The letter "F" in the far left position in the filter box indicates that the Artifact Filter was applied to this ECG.

Monitoring ECG Quality

The HP interpretive cardiograph monitors ECG trace quality throughout the lead attachment, ECG acquisition and analysis process to ensure that you receive the highest possible quality ECG trace. There are four possible ways that trace quality problems are indicated, depending on how your cardiograph is equipped:

- on the patient module display during electrode attachment
- on the preview screen before recording the ECG
- on the keyboard display during analysis
- in the analysis statements on the printed report

In most cases, the operator can use these cardiograph features to eliminate noise quality problems by modifying lead placement or improving patient preparation.

While attaching lead wires to the patient, the operator receives constant feedback about leads with poor contact and noisy lead wires on the patient module display and/or on the preview screen. Electrodes that are off are denoted by an "X" on the patient module display, or a straight line on the preview screen. On the patient module, noisy lead wires are indicated with a series of bars; the taller the bars, the noisier the signal. On the preview screen, noisy lead wires are indicated by poor ECG signals. With this immediate feedback, the operator can correct problems before the ECG trace is acquired, analyzed and printed. This saves the operator time and paper.

The real-time ECG traces in all leads can be viewed on the preview screen before analysis and printing. Three leads are displayed at one time and the operator can scroll through all configured leads in groups of three to check the quality of the actual ECG tracings visually. When an Auto ECG is requested, the preview screen will display the Auto 3x4 ECG tracing that will be analyzed and printed. The operator can press the Stop key and correct visible noise problems.

The HP interpretive cardiograph attempts to preacquire ECG data by immediately using the data from the most recent ten seconds if there is good electrode contact for all leads. Preacquisition saves operator time if good ECG signals are available prior to requesting the Auto ECG.

During analysis, the cardiograph further checks to determine if the trace quality is adequate for good ECG measurements. The ECG is analyzed for muscle artifact, AC noise, baseline wander, and leads-off. Any noise problems not corrected by the operator are detailed in the interpretive statements on the ECG analysis report.

If the noise conditions are sufficient to prevent ECG analysis, the ECG will be printed without analysis. The operator must then correct the noise problem and retake the ECG.

On some PageWriter models, the quality check presents an advisory message on the display. If the data is acceptable on all 12 leads, the message is `ECG ok`. Otherwise, the types of noise and the leads or lead groups in which the noise occurs are indicated. If the noise is severe enough that analysis results could be impaired, then `Retry` is displayed at the end of the advisory message. At this point the operator can press Stop and correct the noise problem before retaking the ECG.

The quality checks available on the HP interpretive cardiograph aid the operator in eliminating noise problems encountered throughout the process of taking an ECG. They allow the operator to correct noise problems by modifying ECG technique before the ECG is printed. The operator can use these features to ensure that a high quality ECG is recorded.

4

The HP ECG Analysis Program

The HP ECG Analysis Program produces precise, accurate and consistent ECG measurements. The program further provides interpretive statements that highlight key areas of concern for your review. However, this tool is more helpful if you understand how and why it works and how you can best use its capabilities. Figure 4-1 shows this process. (Note that Operator Feedback and Extended Measurements report are not available on some PageWriter models.)

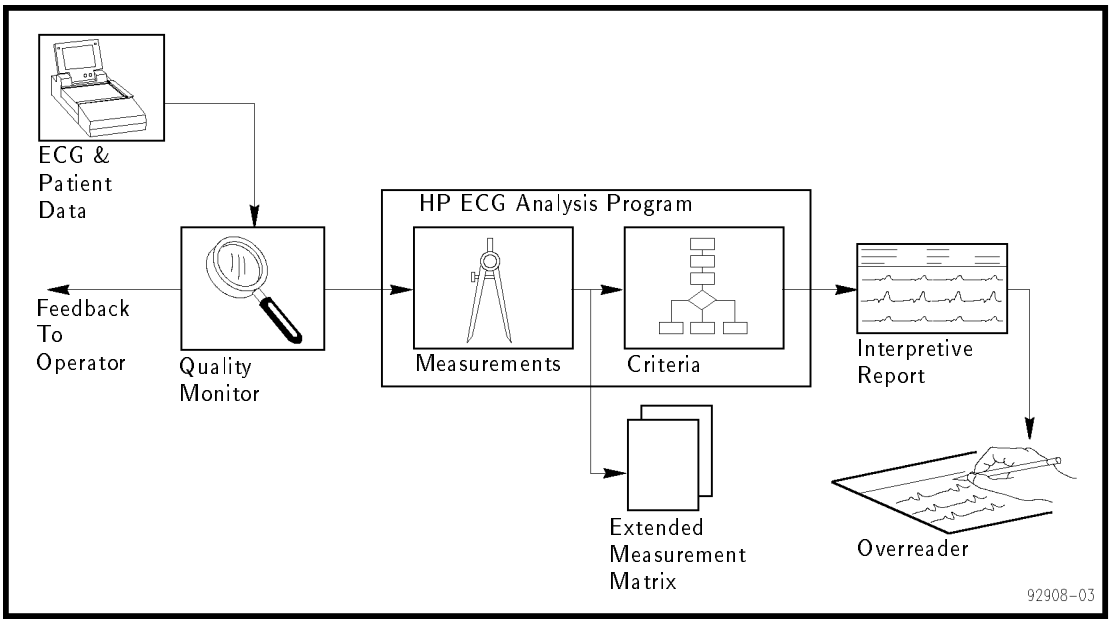

Figure 4-1. The HP ECG Analysis Process.

Understanding the HP ECG Analysis Program

The analysis process begins with the simultaneous acquisition of the ECG's 12 conventional leads. It then proceeds through four steps before producing the interpreted ECG report. These steps are:

1. **Quality Monitor** – examines the technical quality of each ECG lead.
2. **Pattern Recognition** – locates and identifies the various waveform components.
3. **Measurement** – measures each component of the waveform and performs basic rhythm analysis, producing a comprehensive set of measurements.
4. **Interpretation** – uses the extended measurements, with information about the patient such as age and sex, to select those interpretive statements from the criteria program which summarize the findings for the ECG.

Hewlett-Packard provides two standard criteria programs, adult and pediatric, for your HP interpretive cardiograph. Future updates to these programs or entirely new programs can be installed easily in your cardiograph, if is equipped with a flexible disk.

Patient information, including age, sex, height, weight, medications (Rx codes) and previous diagnoses (Dx codes), are used by the criteria programs in selecting the interpretive statements. (Rx codes and Dx codes may not be available on some PageWriter models.)

How the HP Interpretive Cardiograph Measures ECGs

The HP interpretive cardiograph calculates measurements for all the waveforms that you see on the Auto 3x4 report. Every beat in every lead is measured individually, allowing the natural variations among beats to contribute to the representative measurements. This is in contrast to other measurement methods in which a representative beat is constructed and then measurements are made only for the constructed beat. In the HP interpretive cardiograph, representative group, lead and global measurements are calculated from combinations of the comprehensive set of measurements for each beat. The ECG criteria program can use any combination of these three types of measurements, which enhances the flexibility and power of its interpretive capabilities.

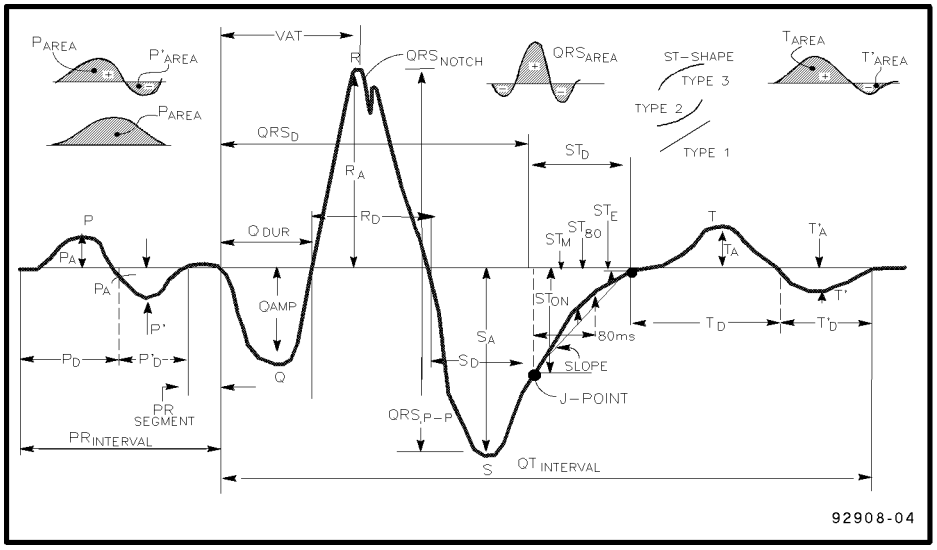

Figure 4-2. ECG Morphology Measurements.

Waveform Recognition

The first step of the measurement program involves waveform recognition and beat detection. A boundary indicator waveform in which QRS complexes and pacemaker spikes are enhanced is derived from all leads over the ten-second analysis period. After the approximate QRS complex and pacemaker spike locations are known, another boundary indicator waveform that enhances P and T wave detection is derived. Approximate P wave, QRS complex and T wave regions are then determined for each beat in the ECG.

Comprehensive Measurements

After the approximate waveform locations are known, they are further refined to determine precise onsets and offsets for each waveform. Once onsets and offsets are known, amplitude, duration, area and shape are calculated for every P wave, QRS complex, T wave and ST segment in every lead that you see on the Auto 3x4 report. Waveform irregularities such as notches, slurs, delta waves and pacemaker spikes are also noted for every beat. A table of all these measurements is created, from which the representative measurements are calculated.

Group Measurements

After all the beats have been measured, each beat in the ECG is classified into one of five rhythm groups based on rate and morphology parameters. Each group consists of beats with similar R-R intervals, durations, and shapes, except that all paced beats are grouped together, regardless of other parameters. Group 1 represents the type of beat that is most normal or predominant and groups 2 through 5 represent other beat types. The group into which each beat is classified is noted under the heading "Rhythm Grouping of Beats" on the Extended Measurements report. Group measurements

are calculated by averaging the measurements for all the beats in each of the groups and are reported in the Rhythm Analysis section of the Extended Measurements report.

Lead Measurements

Representative measurements for each of the 12 leads are calculated from the comprehensive set of measurements for all the beats in the ECG. Only the beats of the predominant group (Group 1) are used. If a particular lead (as shown on the Auto 3x4 report) does not have any Group 1 beats, a beat group with similar parameters is used, if possible. The measurement program tries to select a beat group for which the beats are not paced. Only if all beats in the ECG are paced will the measurements be for paced beats. If there are paced and non-paced beats in an ECG, only the non-paced beats will be measured, which may result in leads for which no measurements are reported.

In each lead, the measurements for all the beats belonging to the selected beat group are averaged. The lead measurements are representative of the dominant waveform present in each lead and are reported in the Morphology Analysis section of the Extended Measurements report.

Atrial Rhythm Analysis

Atrial rhythm is determined by examining leads V1, aVF, II and III in succession until the program can report conclusively that there are multiple P waves, that there are no P waves, or that there is one P wave per QRS complex. If a conclusive result is achieved, then the last lead analyzed will be used to calculate group and global atrial rhythm parameters. If no conclusive result is achieved, no atrial rhythm parameters are calculated.

Global Measurements

The global measurements for the ECG, including the frontal and horizontal plane axis measurements, are reported to the right of the lead measurements in the Morphology Analysis section of the Extended Measurements report.

These interval, duration, and segment measurements are weighted averages of the lead measurements. The global rate reported is the mean ventricular rate over the entire ECG unless the ECG criteria program determines that one of the group mean ventricular rates is more representative of the underlying rhythm.

Axis Measurements

Although it is most convenient to use waveform amplitudes when making axis measurements manually, using the areas of the waveforms yields more accurate results. The HP interpretive cardiograph uses the waveform areas from the lead measurements in calculating the P, QRS and T axes, while the sum of the ST onset, middle and end amplitudes is used in calculating the ST axis. For the frontal plane axis measurements, which use the limb leads, nine lead pairs, all at least 60 degrees apart, are used to estimate the axes. The resulting estimates are examined to ensure that they converge to a single result. If so, they are averaged to form the representative axis measurement. The horizontal plane axis measurements, which use leads V1–V6, are calculated similarly from seven lead pairs.

The representative measurements are reported on the Extended Measurements report. A printed example and a brief explanation of this report are in Chapter 7, **Reading the Printed Report**. Appendix C, **The Extended Measurements Report** explains each of the measurements on the report in more detail.

The ECG Criteria Language (ECL)

The ECG Criteria Language (ECL) is a medically-oriented computer language developed specifically by Hewlett-Packard for the definition of electrocardiographic criteria. First introduced in 1978, the HP ECG Analysis Program, using ECL, was one of the first commercially-available expert systems.

The primary objective of ECL is to allow criteria definition by physicians with little or no knowledge of computer programming. Basically, it provides a way through which ECG criteria may be expressed in a form that both a cardiologist and a computer can read. Consistently-used terminology was chosen to describe ECG criteria for the foundation of ECL. This terminology was chosen from a broad base of users as well as electrocardiography texts.

Categories

At the highest level, criteria expressed in ECL are broken into medically significant categories that are like the chapters of an electrocardiography textbook.

Sentences

Within each category is a series of sentences in which the criteria are expressed. These sentences allow the program to PRINT an interpretive statement when the criteria are met, to SUPPRESS a statement in the presence of a higher-priority statement, to GOTO another point in the program, or to perform calculations and assign (SET) the result to a variable for use later in the program. The PRINT sentence has this form:

PRINT <interpretive statement> IF <medical criteria> ;

For example, the following statement causes an inferior infarct statement to be printed on the report if the criteria are met:

```
PRINT #IMI10 BO
    "Consider inferior infarct"
    . "Small Q waves in II, III, aVF"
    IF (Q:DURATION ... ;
```

where IMI10 is the statement code corresponding to the statement enclosed in quotation marks and BO stands for a severity of borderline significance for this statement. In this example the interpretive statement is "Consider inferior infarct". The reason statement, "Small Q waves in II, III, aVF", summarizes the detailed criteria which follow the IF.

Interpretive statements on the report are preceded by either a ".", as shown in this example, or a "$" or a "*". Statements preceded by a "$" or a "*" call attention to certain technical aspects of the ECG which are of interest to the overreader, but not essential for the final report. These statements are automatically suppressed by the HP 5600C ECG Management system after the ECG report has been confirmed.

A cardiologist reading an ECG can immediately discount many classes of interpretation. However, the computer-based program must check them all sequentially. Within a category, the criteria for interpretive statements become more and more restrictive from beginning to end. Consequently, criteria met for any given ECL statement in a category

automatically suppress any previous statements (in that category) that had been selected for printing. Thus, each category can only be represented on the final report by one statement at most. This statement is the last one encountered whose medical criteria were true based on the measurements, earlier decisions, and patient ID information.

Overall Severity

Each statement selected for the interpretive report has an associated severity. The severities of all selected statements are considered by a set of rules in the criteria program to determine the ECG's overall severity. This severity is printed on each page of the interpretive report.

Further Information

The HP 5600C ECG Management System supports the complete development environment for ECL programs. ECL programs modified or developed on the ECG Management System can be used with the HP interpretive cardiograph. For further information about the ECL programming language, please refer to the *Model 5600C ECG Criteria Language (ECL) Programmer's Reference Manual*.

5

The HP Adult ECG Criteria Program

Development of the Hewlett-Packard Adult ECG Criteria Program began in 1971 as a combined effort between Hewlett-Packard and a worldwide panel of cardiologists. The program is written in the ECG Criteria Language (ECL), which was created by Hewlett-Packard to follow the logical process used by skilled physicians to analyze ECGs. The design of the program and a complete development environment allow it to be modified easily on the HP 5600C ECG Management System.

The adult ECG program was first introduced into the clinical environment in 1978 as part of the HP 5600C ECG Management System. It has evolved through the years into the sophisticated program available today. The program has also been available as part of the Hewlett-Packard PageWriter intelligent cardiograph family since 1983. Now in its eighth release, the Hewlett-Packard adult ECG program has been used worldwide to analyze an estimated 16 million ECGs annually.

Understanding the HP Adult ECG Criteria Program

This chapter contains brief descriptions of the major categories of interpretive statements in the Hewlett-Packard adult ECG program. Reviewing these descriptions will help you understand the program's breadth of scope and depth of analysis in various areas of ECG interpretation. You will then be better able to use Hewlett-Packard's computer-assisted ECG analysis effectively in your daily ECG overreading activities.

The criteria used to select the interpretive statements in this program use the full range of measurements in the measurement matrix. These include durations, amplitudes, areas, and other parameters described in Appendix C, **The Extended Measurements Report**. For clarity and conciseness, the following summaries are not comprehensive. Rather, when describing the criteria logic where the significant values vary, only one measurement value is mentioned and it is labeled "(typical)". The typical value is the one that is most generally applied in the logic. You will then be better able to use Hewlett-Packard's computer-assisted ECG analysis effectively in your daily ECG overreading activities.

In the criteria logic there are many situations in which an interpretive statement that is otherwise qualified to be printed, is suppressed by more significant conditions that override the initial statement. For example, left bundle branch block will prevent the printing of many statements including all of those relating to ventricular hypertrophy, most infarcts, T wave abnormalities, ST deviations, etc. These suppressive conditions generally are not addressed in the categories discussed in this chapter.

The following categories, representing clinically relevant statements and some technical statements and disclaimers, are described in the following sections.

Pediatric Age Disclaimer
Calibration Notice if not Standard
Technical Quality Statements
Electronic Pacemaker
Basic Cardiac Rhythm
Premature Beats (Short R-R)
Pauses (Long R-R Interval)
Miscellaneous Arrhythmias
AV Conduction (PR Interval)
QRS Axis
Ventricular Conduction Delays
Right Atrial Enlargement
Right Ventricular Hypertrophy
Left Atrial Enlargement
Left Ventricular Hypertrophy
Chronic Pulmonary Disease
Inferior Infarct
Posterior Infarct
Lateral Infarct
Anterior Septal and Anterior Infarct
Anterolateral and External Anterior MI
Apical Infarct
Tall T Waves
Drug and Electrolyte Effects
T Wave Abnormalities
Ischemia
ST Segment Depression
Subendocardial Injury
Combined ST and T Abnormalities
Injury and Ischemia
ST Segment Elevation
Severity

Pediatric Age Disclaimer

The Hewlett-Packard Adult ECG criteria program is intended for use on ECGs of adults. The Hewlett-Packard Pediatric ECG criteria are selected for use on ECGs of patients under 16 years old. If adult criteria are selected and if the patient is less than 16 years old, a statement is printed to remind you that no attempt will be made to interpret signs of infarction or ST–T abnormalities.

On the cardiograph, the patient's age can be entered in units of hours, days, weeks, months, or years. It also may be entered as the year of birth, in which case an age in years will be calculated by the cardiograph.

If the age is entered improperly or not at all, the patient is assumed to be more than 35 years old.

Calibration Notice if Not Standard

This category checks the calibration pulse in each channel of the ECG. Except for the case where both the limb leads and the precordial leads are at standard calibration (10 mm/mV), a statement describing the calibration for the ECG is included in the report.

Table 5-1. Calibration

Calibration	Nominal Value	Allowed Range	±%
Half standard	5 mm/mV	4.75–5.25 mm/mV	5%
Standard	10 mm/mV	9.5–10.5 mm/mV	5%
Double standard	20 mm/mV	19.0–21.0 mm/mV	5%

Technical Quality Statements

This category contains non-clinical statements which are intended to identify ECGs with technical problems and prevent them from being interpreted by the medical criteria.

Electronic Pacemaker

This category relies on the ECG measurements to detect paced ECGs. For ECGs which are predominantly-paced there is no further consideration of medical criteria. For demand-paced ECGs in which there are enough non-paced beats, no further rhythm analysis is attempted. However, the non-paced beat measurements are used in the remaining categories to check for other abnormalities in the ECG.

Basic Cardiac Rhythm

One statement describing the basic cardiac rhythm is selected from this category based on the morphology and rhythm measurements made from the ECG.

Interpretive statements regarding the basic cardiac rhythm are generated based on the interrelationships of the various measurements and determinations. These statements include those related to:

- Tachycardia, bradycardia, and varying rate
- Sinus, atrial, supraventricular, junctional and ventricular rhythms
- Second and third degree AV block (first degree block is addressed in the AV Conduction category)
- AV dissociation
- Atrial fibrillation
- Atrial flutter
- Bigeminy and Trigeminy patterns

A normal P axis measurement (−30 to 120 degrees in the frontal plane) is assumed to indicate a sinus-originated P wave while an abnormal P axis signifies an atrial or a junctional origin.

Tachycardia is generally defined as a rate of 100 beats per minute (bpm) or higher; bradycardia as slower than 50 bpm. For a more definitive discussion of tachycardia and bradycardia see the recommendations of the "Task Force on Standardization of Terminology and Interpretation" as published in the *American Journal of Cardiology*, January 1978.

Premature Beats (Short R-R)

Interpretive statements in this category relate to premature beats. These are recognized when the preceding R-R interval is shorter than the average R-R interval of a background ventricular rate that is basically regular. A 15% (typical) or greater reduction in R-R interval is considered significant.

Premature beats with normal QRS duration (QRSD) are considered to be atrial or junctional in origin depending on the presence or absence of a P wave. Those with longer than normal QRSD are considered to be either ventricular in origin or to be aberrant supraventricular in origin.

Pauses (Long R-R)

Long R-R intervals are significant if they are more than 140% (typical) of the average R-R in a background ventricular rate that is basically regular. They are considered to indicate either a sinus arrest or an intermittent AV block. Interpretive statements in this category indicate either escape beats or types of second degree AV block.

The presence or absence of a P wave as well as the duration of the QRS indicates the origin of an escape beat. Atrial and supraventricular escapes will show a P wave and a normal QRSD. Junctional escape will show no P wave, but a normal QRSD. A prolonged QRSD indicates a ventricular origin of the escape beat.

Different second degree AV blocks are indicated on the basis of more P waves than QRS complexes. A statement indicating Mobitz I (Wenckebach) second degree AV block depends on progressively longer PR intervals preceding the long R-R interval.

Miscellaneous Arrhythmias

This category provides interpretive statements related to arrhythmias that are not covered in the preceding Basic Cardiac Rhythm, Premature Beats, or Pauses categories.

Statements relating to interpolated beats depend on the measurement program recognizing that such beats are present. It recognizes the beats if there are consecutive R-R intervals that are approximately one half the average R-R of a background ventricular rate that is basically regular.

Aberrant complexes are recognized when the R-R interval is only slightly decreased but the QRSD is prolonged, as if it were of ventricular origin.

AV Conduction (PR Interval)

All statements in this category are based on the measurement of a prolonged PR interval, with the exception of one statement which identifies ECGs with accelerated AV conduction.

The PR interval varies slightly according to age and heart rate. The following table defines the limits:

Table 5-2.
Borderline and Abnormally Prolonged PR Intervals (ms)

Age (years)	Heart Rate (bpm)			
	1–50	51–90	91–120	over 120
0–15	200–210	190–200	185–195	180–190
16–60	210–220	200–210	195–205	190–200
over 60	220–230	210–220	205–215	200–210

Left Value = PR Interval Upper Limit (Borderline)

Right Value = PR Interval Upper Limit (1st degree AV Block)

QRS Axis

The mean electrical vector (mean QRS axis) is calculated in the frontal and horizontal planes. The normal frontal axis range varies with age and body build. The frontal QRS axis in young persons will tend to the right. The frontal QRS axis in old persons will tend to the left. In addition, the QRS axis in thin persons will tend to be more to the right than in heavy persons. A frontal QRS axis between −30 and +90 degrees is considered normal, generally subject to modification by age and build. Frontal QRS axis measurements counterclockwise from −30 will be considered to be deviated to the left and those clockwise from +90 will be considered to be deviated to the right.

Interpretive statements based on frontal QRS axis measurements are made describing left and right deviation as well as superior, horizontal, and vertical directions.

Statements involving posterior axis, arm lead reversal and dextrocardia are based on the horizontal plane axis measurements as well as the frontal plane measurements.

These statements are skipped if the ECG is paced, if the patient is in a ventricular rhythm or if the mean QRS axis is well within the normal range (30 to 80 degrees, clockwise, in the frontal plane).

Ventricular Conduction Delays

A QRS duration (QRSD) greater than 100 ms is common to all of the interpretations in this category except for isolated Left Anterior Fascicular Block (LAFB) and Left Posterior Fascicular Block (LPFB) which are present in the absence of a prolonged QRS. Otherwise, any definitive block interpretation requires that the QRSD exceed 120 ms. A QRSD between 110 and 120 ms is considered incomplete block and between 100 and 110 ms is considered marginal intraventricular conduction delay.

LAFB interpretations are associated with leftward deviation of the mean frontal QRS axis between −40 and 240 (typical) degrees counterclockwise.

interpretations are associated with rightward deviation of the mean frontal QRS axis between 120 and 210 (typical) degrees clockwise.

RBBB interpretations are always associated with the terminal portion of the QRS being directed to the right, i.e. dominant negative (Q, S) forces in I, aVL, and V6 and positive forces in V1.

LBBB interpretations are always associated with the terminal portion of the QRS being directed to the left, i.e. dominant positive (R, R′) forces in I, aVL and V6 and negative forces (Q, S) in V1.

LAFB and LPFB may be recognized in combination with RBBB.

The Wolff-Parkinson-White conduction abnormality is also recognized in this category based on the occurrence of delta waves in multiple leads and a QRS duration more than 100 ms. A short PR (PR segment $<$ 55 ms or PR interval $<$ 120 ms) reduces the required number of leads with delta waves required to detect this condition.

Right Atrial Enlargement

Large P waves are considered suggestive of RAE. The minimum voltage considered significant is 0.24 mV (typical). P wave duration and amplitude are examined in all leads.

Larger P waves lead to more severe interpretive statements regarding the likelihood of RAE.

Right Ventricular Hypertrophy

Right ventricular hypertrophy statements are made on the basis of the presence of several findings:

- The presence of a prominent R or R′ in lead V1
- The presence of a prominent negative voltage in either of leads I or V6
- Right atrial enlargement
- Right axis deviation in the frontal plane
- ST–T changes characteristic of RVH

The statements to be printed regarding RVH are determined by the combinations of the above findings. Stronger statements result when multiple findings are present.

Prominent R or R′ in V1

An R that is more than 75% the size of the Q or S is significant. An R′ larger than 20 ms and 0.30 mV is significant. A QRS with a positive component larger than the negative component (i.e., a positive QRS area) is highly significant.

Prominent Q or S in I or V6

A Q, S, or S′ larger than 40 ms and 0.20 mV is significant. A QRS with a negative component larger than the positive component (i.e., a negative QRS area) is highly significant.

Right Atrial Enlargement

This finding is determined by the presence of RAE from the Right Atrial Enlargement category.

Right Axis Deviation in the Frontal Plane

This finding is determined by a frontal QRS axis between 111 and 269 degrees (clockwise).

ST-T Changes Characteristic of RVH

This finding is determined by an examination of leads II, aVF, V1, V2, and V3 for the presence of negative ST and T values typical of the right ventricular strain pattern.

Left Atrial Enlargement

All leads are examined for the duration and the amplitude of both the initial and terminal portions of a biphasic P wave. Durations over 110 ms combined with amplitudes over 0.10 mV are considered significant though not necessarily abnormal unless they are present in multiple leads. A notched P wave adds to the significance of the other values.

Lead V1 is specifically examined for duration, amplitude and area of the negative component of the T wave. Though durations of over 30 ms and amplitudes over 0.09 mV can be considered significant, the area of this negative component must be greater than 0.60 Ashman

units to be considered LAE. An Ashman unit is the area of 1 square millimeter at normal speed (25 mm/sec) and normal sensitivity (10 mm/mV). An Ashman unit equals 40 ms x 0.1 mV.

Left Ventricular Hypertrophy

Left Ventricular Hypertrophy statements are made on the basis of a point score derived from several findings:

- High voltage in QRS components
- Left axis deviation in the frontal plane
- Left atrial enlargement
- ST–T changes characteristic of LVH
- Prolonged QRS duration or ventricular activation time (VAT)

Higher point scores result in more severe statements regarding the likelihood of LVH.

High Voltage in QRS Components

Voltage values for the QRS components that are considered excessively high vary with the leads involved and whether the deflection is positive or negative. In frontal leads the minimum value that is considered excessive is a positive deflection of more than 1.20 mV in lead aVL.

Precordial leads V1 and V2 are examined for negative deflections (Q or S) and V5 and V6 are examined for positive deflections (R or R′). These values are considered individually and any value greater than 2.50 mV is considered significant. In addition, the negative values in V1, V2 and the positive values in V5, V6 are added together. Any total for Q or S in V1 plus R or R′ in V5 or V6 that exceeds 3.50 mV is significant. A total of Q or S in V2 plus R or R′ in V5 or V6 must exceed 4.0 mV to be significant.

Higher voltages will result in more points for qualifying statements regarding LVH.

Because higher voltages are normal for young persons, age is given consideration in the recognition of LVH. The younger the patient, the more stringent are the requirements for an LVH statement.

Left Axis Deviation in the Frontal Plane

This finding is determined by a frontal QRS axis between −31 and −90 in the absence of any statement indicating either anterior fascicular block or inferior infarct.

Left Atrial Enlargement

This finding is determined by a statement from the Left Atrial Enlargement category indicating the presence of LAE. This feature is ignored in the presence of mitral valvular disease, atrial flutter, or atrial fibrillation.

ST-T Changes Characteristic of LVH

This finding is determined by an examination of leads I, aVL, V4, V5, and V6 for the presence of negative ST and T values typical of the left ventricular strain pattern.

A Prolonged QRS Duration or Ventricular Activation Time

This finding is determined by a QRS duration of 95 to 120 ms, and a VAT longer than 55 ms. It is ignored if any bundle branch block statement has been made.

The statements to be printed regarding LVH are determined by the combinations of the above findings that are present.

Chronic Pulmonary Disease

All frontal leads are examined for QRS peak-to-peak voltage. If no lead has a value exceeding 0.60 mV the ECG is considered borderline low voltage. If no value exceeds 0.50 mV the ECG is considered definite low voltage, an abnormal finding.

All precordial leads are examined for QRS peak-to-peak voltage. If no lead has a value exceeding 1.00 mV the ECG is considered definite low voltage, an abnormal finding.

Combinations of low voltage statements, and the presence of rightward deviation of the frontal P and QRS axes and right atrial enlargement, may lead to statements suggesting the likelihood of chronic pulmonary disease.

Inferior Infarct

Leads II, III. and aVF are examined for Q wave presence and size (amp x dur), the relative amplitudes of the Q and R, the presence of T wave changes (flattened or inverted), and the presence of an elevated or depressed ST segment.

As the Q waves become larger and/or show in more leads, and the R waves become less prominent the interpretive statements become stronger.

For inferior Q waves to be considered significant, at least one of them must be longer than 25 ms in duration and more than 1/6 the amplitude of the associated R. For any infarct statement to qualify, at least one Q wave must be longer than 35 ms and more than 1/5 the amplitude of the R wave.

A leftward direction of the axis of the initial portion of the QRS adds to the likelihood of an inferior infarct statement.

T wave and ST changes are used to estimate the age of the infarct. Increased T wave inversion and larger ST segment deviations will generate statements indicating more recent infarction.

Sex and age influence the detection of inferior infarct in that being male and/or young makes normal Q waves more likely in the inferior leads.

Posterior Infarct

Leads V1 and V2 are examined for the relative and absolute sizes of the R and S waves, an absent or insignificant Q wave (less than 10 ms and 0.05 mV), and a positive T wave. A prominent R (typical is three times the size of the S), in the presence of an insignificant Q (typical is $<$ 10 ms, $<$ 0.05 mV), and an upright T, might generate a statement suggesting the likelihood of a posterior infarct (PMI). There are no statements definitely indicating the presence of a PMI. In evaluating the significance of the R wave, the duration is given more emphasis than the amplitude.

Indications of LVH or RVH will decrease the likelihood of a PMI statement.

Sex and age influence the detection of a posterior infarct in that being male and/or young makes prominent R waves more likely in V1 and V2.

Lateral Infarct

Leads I, aVL, V5 and V6 are examined for Q wave presence and size (amp x dur), the relative amplitudes of the Q and R, the presence of T wave changes (flattened or inverted), and the presence of an elevated or depressed ST segment.

For lateral Q waves to be considered significant there must be at least one that is longer than 35 ms and more than 0.10 mV in amplitude. In addition it must have an amplitude that is at least 20% as large as that of the R wave.

As the Q waves become larger and/or show in more leads, and the R waves become less prominent, the interpretive statements become stronger.

T wave and ST changes are used to estimate the age of the infarct. Increased T wave inversion and larger ST segment deviations will generate statements indicating more recent infarction.

Sex and age influence the detection of lateral infarct in that being male or young or both makes normal Q waves more likely in the lateral leads.

Anteroseptal and Anterior Infarct

Leads V1, V2, V3, and V4 are examined for Q wave presence and area, the relative and absolute sizes of the R and S, whether the QRS area is negative or positive, the presence of T wave changes (flattened or inverted), and the presence of an elevated or depressed ST segment.

For any anteroseptal or anterior Q wave to be considered significant, it must be longer than 30 ms (typical) in duration and over 0.07 mV in amplitude.

Positive findings that occur in V1 and V2 will tend to be reported as anteroseptal statements while those that occur in V3 and V4 will tend to be reported as anterior statements.

As the Q waves become larger and/or show in more leads, and the QRS progression from negative to positive becomes more shifted laterally, the interpretive statements become stronger for infarction in the anterior region.

T wave and ST changes are used to estimate the age of the infarct. Increased T wave inversion and larger ST segment deviations will generate statements indicating more recent infarction.

Anterolateral and Extensive Anterior Infarct

Leads V3, V4, V5, and V6 are examined for Q wave presence and size (amp x dur), the relative and absolute sizes of the R and S, whether the QRS area in V3 is negative or positive, the presence of T wave changes (flattened or inverted), and the presence of an elevated or depressed ST segment.

For any anterolateral Q wave to be considered significant it must be longer than 30 ms (typical) in duration and over 0.07 mV in amplitude.

As the Q waves become larger and/or show in more leads, the interpretive statements become stronger for infarction.

Positive findings in all six precordial leads will lead to statements describing extensive anterior infarct conditions.

Sex and age influence the detection of anterolateral infarct in that being male and/or young makes normal Q waves more likely in the anterolateral leads.

T wave and ST changes are used to estimate the age of the infarct. Increased T wave inversion and larger ST segment deviations will generate statements indicating more recent infarction.

Apical Infarct

Only one statement is contained in this category and it indicates an apical infarct in the presence of significant Q waves (> 25 ms, > 0.10 mV) in four of these five leads: II, aVF, V4, V5, and V6.

Tall T Waves

All leads are examined for the presence of positive T waves with amplitudes that exceed 1.20 mV, or for positive T waves that exceed 0.50 mV and are also more than half the size of the peak-to-peak QRS voltage. The presence of such T waves can lead to statements calling attention to the possibility of metabolic, electrolyte or ischemic abnormalities.

Drug and Electrolyte Effects

Measurements of QT interval as corrected for heart rate, and measurements associated with ST segment depression and T wave changes are examined for values characteristic of the effects of quinidine, procainamide, digitalis and abnormal calcium and potassium levels.

Interpretive statements are made calling attention to the possible correlation between the findings and clinical conditions.

The presence of an Rx code indicating use of quinidine, procainamide or digitalis will favor interpretive statements calling attention to the findings compatible with the effects of those drugs.

T Wave Abnormalities

All leads are examined for T wave amplitude, the relative amplitude of the T and the QRS, and whether the T is negative or positive. The frontal axis of the T wave and its relation to the frontal QRS axis is also measured.

Reduced T wave amplitude, both absolute and relative to the QRS, as well as negative T waves, are considered to be abnormal findings. Minimal changes in one or a few leads will lead to less severe statements. As the changes become more prominent in magnitude and the number of affected leads increase, the statements become more severe.

A frontal T axis that is not between −10 and 100 degrees or a QRS-T angle greater than 90 degrees may result in a statement indicating nonspecific T wave abnormalities.

ECGs of persons younger than 16 years are excluded from the least severe statements because such T wave findings can be considered normal.

Whenever possible the location of T wave abnormalities will be indicated as part of the interpretive statements. Though not rigidly defined, the localization will generally fit the following:

Table 5-3. T Wave Abnormality Localization

Location	I	II	III	aVR	aVL	aVF	V1	V2	V3	V4	V5	V6
Anterior								X	X	X		
Anterolateral	X				X			X	X	X	X	X
Lateral	X				X						X	X
Inferior		X	X			X						

A concurrent statement regarding RVH, LVH, LBBB, RBBB, any infarct, or any statement associated with drug therapy or electrolyte imbalance will impact this category by tending to suppress T wave statements. This is more true for the less severe T wave statements than for the more severe T wave statements.

Ischemia

This category contains statements calling attention to the likelihood of ischemia. None of these statements involve any new examination of measurements. All ischemia statements in this category are determined by the qualification of a statement or combination of statements in the preceding category, T Wave Abnormalities. The degree of likelihood of ischemia is based on the severity of the qualifying T wave statements.

ST Segment Depression

All leads are examined for negative values in the ST segment. The values examined include the following points in the ST segment:

- The onset of the ST segment (the J point)
- The point midway between the onset and the end of the ST segment
- 80 ms past the J point
- The end of the ST segment (the beginning of the T wave)

Besides negative values in the ST segment, other features are examined:

- The slope of the ST segment in degrees
- The shape of the ST segment (straight, concave up or concave down)

The smallest negative ST deflection considered significant is 0.03 mV.

As the negativity of the ST segment increases, more severe statements are generated. Minor depression of the segment produces statements with a severity code of Otherwise Normal. Increasing depression produces statements progressing through Borderline to Abnormal.

Whenever possible the location of ST abnormalities will be indicated as part of the interpretive statements. Though not rigidly defined, the localization will generally fit the following:

Table 5-4. ST Segment Depression Localization

Location	I	II	III	aVR	aVL	aVF	V1	V2	V3	V4	V5	V6
Anterior								X	X	X		
Anterolateral	X			X	X			X	X	X	X	X
Lateral	X				X						X	X
Inferior		X	X			X						

A concurrent statement regarding RVH, LVH, LBBB, RBBB, any new infarct, or any statement associated with drug therapy or electrolyte imbalance will impact this category by tending to suppress ST depression statements. This is more true for the less severe ST depression statements than for the more severe ones.

Subendocardial Injury

This category contains statements calling attention to the likelihood of subendocardial injury. None of these statements involve any new examination of measurements. All subendocardial injury statements in this category are determined by the qualification of a statement or combination of statements in the preceding category, ST Segment Depression. The degree of likelihood of subendocardial injury is based on the severity of the qualifying ST depression statements.

Combined ST and T Abnormalities

This category contains statements calling attention to the presence of both ST segment and T wave changes. None of these statements involve any new examination of measurements. All statements in this category are determined by the qualification of a combination of statements in the T Wave Abnormalities and ST Segment Depression categories. The severity of the statements in this category are dependent on the severity of the qualifying ST and T wave changes.

Injury and Ischemia

This category contains statements calling attention to the possibility of subendocardial injury and/or ischemia. None of these statements involve any new examination of measurements. All statements in this category are determined by the qualification of a combination of statements in the T Wave Abnormalities and ST Segment Depression categories.

ST Segment Elevation

All leads are examined for positive values in the ST segment and for negative T waves. The ST segment measurements examined include the deflection at the onset of the ST segment (the J point), and the deflection at a point 80 ms after the J point. The slope of the ST segment in degrees is also examined.

The smallest positive ST deflection considered significant is 0.05 mV.

When ST elevation is small (0.05 mV to approximately 0.25 mV) the statements are considered of Borderline severity while larger deflections are considered to be Abnormal.

When inverted T waves are associated with ST elevation, the statement will include subepicardial injury as a possibility.

If many leads show ST elevation, the statement will include pericarditis as a possibility.

Whenever possible, the location of ST elevation and subepicardial injury will be indicated as part of the interpretive statements. Though not rigidly defined, the localization will generally fit the following:

Table 5-5. ST Segment Elevation Localization

Location	I	II	III	aVR	aVL	aVF	V1	V2	V3	V4	V5	V6
Anterior								X	X	X		
Anterolateral	X				X			X	X	X	X	X
Lateral	X				X						X	X
Inferior		X	X			X						

Severity

This is the final category of the ECL program. The overall severity for the entire ECG is determined based on the severity of the statements which have been selected for the report. Each statement which appears on the ECG report carries one of the following severities:

NO – Normal

ON – Otherwise Normal

BO – Borderline

AB – Abnormal

DE – Defective

NS – No Severity Assigned

The severity that is assigned to the ECG interpretive report as a whole is generally the same as the most severe statement in the report. The severity may be advanced one level from Otherwise Normal to Borderline or from Borderline to Abnormal if three or more statements on the report have the lesser severity.

6

The HP Pediatric ECG Criteria Program

Pediatric ECG interpretation criteria are particularly well-suited for computer-assisted analysis because of their complex, age-dependent nature. Development of the Hewlett-Packard Pediatric ECG Criteria Program began in 1975 as a natural adjunct to the adult program. The program is written in the ECG Criteria Language (ECL) which was created by Hewlett-Packard to follow the logical process used by skilled physicians to analyze ECGs. The design of the program and a complete development environment allow it to be modified easily on the Hewlett-Packard ECG Management System.

The pediatric ECG program was first introduced into the clinical environment in 1983 as part of the Hewlett-Packard ECG Management System and the PageWriter cardiograph.

Understanding the H-P Pediatric ECG Criteria Program

This chapter contains brief descriptions of the major categories of interpretive statements in the Hewlett-Packard pediatric ECG program. Reviewing these descriptions will help you understand the program's breadth of scope and depth of analysis in various areas of ECG interpretation. You will then be better able to use Hewlett-Packard's computer-assisted ECG analysis effectively in your daily ECG overreading activities.

The criteria used to select the interpretive statements in this program use the full range of measurements in the measurement matrix. These include durations, amplitudes, areas, and other parameters described in Appendix C, **The Extended Measurements Report**. For clarity and conciseness in the summaries that follow, the detailed logic of the program will not be described. Rather, when describing the criteria logic where the significant values vary, only one measurement value will be mentioned and it will be labeled "(typical)". The typical value is the one that is most generally applied in the logic.

In the criteria logic there are many situations in which an interpretive statement that is otherwise qualified to be printed, is suppressed by other qualifying conditions that override the initial statement. These suppressive conditions generally are not addressed in the categories discussed in this chapter.

The following categories, representing clinically relevant statements and some technical statements and disclaimers, are described in the following sections.

Pediatric ECG Interpretation
Calibration Notice if not Standard
Technical Quality Statements
Electronic Pacemaker
Dextrocardia
Sinus Rhythms
Atrial Premature Complex
Ventricular Premature Complex
PR Interval
Wolff-Parkinson-White Syndrome
Ventricular Conduction Delay
Right Bundle Branch Block
Left Bundle Branch Block
Right Atrial Enlargement
RVH: QRS Voltage Criteria
Right Axis Deviation
RVH: T Wave Criteria
Right Ventricular Hypertrophy
Left Atrial Enlargement
LVH: QRS Voltage Criteria
Left Axis Deviation
LVH: ST Segment and T Wave Criteria
Left Ventricular Hypertrophy
Biventricular Hypertrophy
Anterior ST Elevation
Inferior ST Elevation
Anterolateral ST Elevation
Anterior ST Depression
Inferior ST Depression
Anterolateral ST Depression
Anterior T Wave Changes
Inferior T Wave Changes
Anterolateral T Wave Changes
Anatomical Diagnoses
Severity

Pediatric ECG Interpretation

The Hewlett-Packard Pediatric ECG criteria program is intended for use on ECGs of children from birth to age 15. If an age is entered that is invalid, the interpretation will be based on an assumed age of 15 years. A special statement noting this assumption is printed instead of the standard notice that the ECG is being interpreted with pediatric criteria.

The patient's age can be entered at the cardiograph in units of hours, days, weeks, months, or years. It also may be entered as the year of birth, in which case an age in years will be calculated by the cardiograph.

Calibration Notice if Not Standard

This category checks the calibration pulse in each channel of the ECG. Except for the case where both the limb leads and the precordial leads are at standard calibration (10 mm/mV), a statement describing the calibration for the ECG is included in the report.

Table 6-1. Calibration

Calibration	Nominal Value	Allowed Range	±%
Half standard	5 mm/mV	4.75–5.25 mm/mV	5%
Standard	10 mm/mV	9.5–10.5 mm/mV	5%
Double standard	20 mm/mV	19.0–21.0 mm/mV	5%

Technical Quality Statements

This category contains non-clinical statements which identify ECGs with technical problems and prevent them from being interpreted by the medical criteria program.

Electronic Pacemaker

This category relies on the ECG measurements to detect ECGs which are paced. For ECGs which are predominantly-paced there is no further consideration of medical criteria. For demand-paced ECGs in which there are enough non-paced beats, no further rhythm analysis is attempted. However, the non-paced beat measurements are used in the remaining categories to check for other abnormalities in the ECG.

Dextrocardia

Dextrocardia is suggested if the frontal P axis is between 90 and 180 degrees, and either lead I or V6 has a small negative P wave, and both leads I and V6 have a large S wave (> 0.6 mV), and the P wave is larger in lead II than in lead III.

Basic Cardiac Rhythm

One statement describing the basic cardiac rhythm is selected from this category based on the morphology and rhythm measurements made from the ECG.

Interpretive statements regarding the basic cardiac rhythm are generated based on the interrelationships of the various measurements and determinations.

Sinus Rhythms

Sinus versus atrial rhythm statements are based on the frontal P axis. If the P axis is between 0 and 90 degrees the rhythm is considered to be of sinus origin. Outside this range the rhythm is considered to be either atrial or supraventricular.

Sinus arrhythmia is detected when there is a minor but significant variation in rate within the ten second period analyzed, and the P axis is normal.

Heart rates slower than the normal range are considered bradycardia and those higher are considered tachycardia as shown in the table below:

Table 6-2.
Age vs. Ventricular Rate for Sinus Rhythms

	Heart Rate (bpm)		
Age Range	**Bradycardia**	**Normal**	**Tachycardia**
0 – 23 hours	$\leq$ 93	94–145	$\geq$ 146
1 – 7 days	$\leq$ 99	100–175	$\geq$ 176
8 – 30 days	$\leq$ 114	115–190	$\geq$ 191
1 – 2 mo.	$\leq$ 123	124–190	$\geq$ 191
3 – 11 mo.	$\leq$ 109	110–178	$\geq$ 179
1 – 2 yr.	$\leq$ 97	98–163	$\geq$ 164
3 – 4 yr.	$\leq$ 64	65–132	$\geq$ 133
5 – 7 yr.	$\leq$ 64	65–115	$\geq$ 116
8 – 11 yr.	$\leq$ 59	60–107	$\geq$ 108
12 – 15 yr.	$\leq$ 59	60–102	$\geq$ 103

Atrial Premature Complex

If there is a beat with essentially the same morphology as the basic background beat but with a rate that is faster (thus, premature), an interpretive statement is made for a premature atrial complex. More than one of this type beat within the ten seconds analyzed will produce a statement regarding multiple premature atrial complexes.

Ventricular Premature Complex

An interpretive statement is made for premature ventricular complex if there is a beat that has a longer QRS duration than the background complex, has an aberrant shape and a faster rate (thus, premature). More than one of this type beat within the ten seconds analyzed will produce a statement regarding multiple premature ventricular complexes.

PR Interval

Upper limits for a normal PR interval vary from 130 ms in a newborn to 180 ms in a 15 year old. PR intervals longer than the upper limit for the patient's age will produce a statement regarding prolonged PR interval for age. However, a PR interval of 210 ms or longer will, in all age groups, produce a statement regarding first degree AV block.

Wolff-Parkinson-White Syndrome

The presence of delta waves along with a shortened PR interval (less than 120 ms) and a QRS duration longer than 90 ms will produce a statement regarding Wolff-Parkinson-White syndrome.

Ventricular Conduction Delay

A QRS duration between 100 ms and 190 ms in a patient less than one year, or a QRS duration between 110 ms and 190 ms in a patient 1 to 15 years old will produce a statement regarding ventricular conduction delay for age.

Right Bundle Branch Block

The presence of a ventricular conduction delay for age and either an RSR′ or no negative component at all (no Q or S) in V1 will produce a right bundle branch block statement. In order for the RSR′ to be significant, the R′ must be at least 20 ms in duration and 0.15 mV in amplitude.

Left Bundle Branch Block

A statement indicating left bundle branch block will be made in the presence of:

- a ventricular conduction delay for age,
- a QRS axis for the terminal 40 ms between −90 and +90 degrees (clockwise),
- a short (< 20 ms) or absent S in I, aVL, V5, V6, and
- a small or absent R wave in V1, V2, V3.

In the absence of a statement regarding LBBB, a mean QRS axis between −60 and −90 degrees will result in a left anterior superior fascicular block statement.

Right Atrial Enlargement

High amplitude P waves will produce a right atrial enlargement statement. Leads I, II, III, aVF, V1, and V2 are examined. At least one must have a P wave larger than 0.25 mV in amplitude with a P wave larger than 0.20 mV in another lead as confirmation.

RVH: QRS Voltage Criteria

Six different age groups are established with appropriate voltage criteria for each group. A total of 24 different conditions meet the criteria for the presence of adequate RVH voltage in the varying age groups. Factors considered in meeting these conditions are:

- the absolute size of R and R′ in V1 and/or V2
- the absolute size of S in V6
- the relative sizes of R and S in V1 and/or V6
- the presence of a QR pattern in V1

This category is bypassed in the presence of any RBBB statement.

Right Axis Deviation

The mean QRS axis is considered in making the determination of right axis deviation (RAD). Three age groups with three different ranges for RAD are established as follows:

- Birth to 5 days: 181 to 269 degrees clockwise
- 6 days to 30 days: 161 to 269 degrees clockwise
- 1 month to 15 years: 135 to 269 degrees clockwise

RVH: T Wave Criteria

RVH T wave criteria are met as follows:

5 days to 4 years	V1 T wave amplitude $> +0.10$ mV, and both V5 and V6 T wave amplitude > 0.01 mV, and no T′ in either V1, V5 or V6
5 to 8 years	V1 T wave amplitude > 0.15 mV, and both V5 and V6 T wave amplitude > 0.01 mV, and no T′ in either V1, V5 or V6

Right Ventricular Hypertrophy

The detection of RVH is made on the basis of the presence of qualifying statements in the RVH Voltage, RAD, and RVH T Wave Criteria categories. Various combinations of statements from these categories will produce statements varying in severity from borderline to abnormal. The likelihood of RVH increases as the severity of the qualifying statements increases.

Left Atrial Enlargement

A large negative component to the P wave in V1 is used to call attention to the likelihood of left atrial enlargement. Negative P waves longer than 40 ms in duration and larger than 0.08 mV in amplitude are significant when they combine to produce a negative area of more than 4.00 ms-mV.

LVH: QRS Voltage Criteria

Values considered significant as LVH voltages are:

S amplitude more than 2.5 mV in V1
S amplitude more than 3.5 mV in V2
R amplitude more than 3.0 mV in V5
R amplitude more than 2.3 mV in V6
R amplitude more than 3.0 mV in I, II, aVL, or aVF
S amplitude more than 2.5 mV in V1
S amplitude in V1 plus R amplitude in V5 more than 4.5 mV
A combination of a 0.40 mV Q and a 1.0 mV R in either V5 or V6

These LVH voltage criteria are used regardless of the patient's age. This category is bypassed in the presence of RBBB or LBBB.

Left Axis Deviation

The mean QRS axis is considered in making the determination of left axis deviation. Four age groups with different ranges for LAD are established as follows:

- Birth to 30 days: −90 to +60 degrees clockwise
- 1 to 2 months: −90 to +40 degrees clockwise
- 3 to 5 months: −90 to +20 degrees clockwise
- 6 months to 15 years: −90 to 0 degrees clockwise

LVH: ST Segment and T Wave Criteria

Leads I, aVL, V4, V5, and V6 are examined for ST segment and T wave changes characteristic of LVH. Positive findings are of two types:

a mid ST segment elevation, with a large positive T wave or:

a slight mid ST segment depression that is upsloping, with a negative T wave.

Left Ventricular Hypertrophy

The determination of LVH is made on the basis of the presence of qualifying statements in the LVH Voltage, LAD, and LVH ST Segment and T Wave Criteria categories. Various combinations of statements from these categories will produce statements of varying severity and certainty regarding the presence of LVH.

Biventricular Hypertrophy

Associated RVH should be considered when any LVH statement is combined with a large R ($>$ 1.0 mV) in V1. Similarly, associated LVH should be considered when RVH statements are combined with both a significant Q wave ($>$ 10 ms and $>$ 0.07 mV) and a large R wave ($>$ 1.0 mV) in V6. Biventricular hypertrophy should also be considered when the combined amplitudes of R and S exceed 6.0 mV in two of leads V2, V3, or V4.

Anterior ST Elevation

Leads V2, V3, V4, and V5 are examined for ST elevation. ST elevation of more than 0.15 mV in these leads produces a statement suggesting a normal variation.

Inferior ST Elevation

Leads II, III, and aVF are examined for ST elevation. ST elevation of more than 0.15 mV in these leads produces a statement suggesting nonspecific ST changes that are probably normal.

Anterolateral ST Elevation

Leads I, aVL, V2, V3, V4, V5, and V6 are examined for ST elevation. ST elevation of more than 0.15 mV in these leads produces one of two statements. One suggests normal variation; the other is of borderline severity and suggests probable association of ST changes with LVH.

Anterior ST Depression

Leads V2, V3, V4 and V5 are examined for ST depression. ST depression of more than 0.20 mV in these leads produces a statement suggesting possible subendocardial injury.

Inferior ST Depression

Leads II, III, and aVF are examined for ST depression. ST depression of more than 0.20 mV in these leads produces a statement suggesting possible subendocardial injury.

Anterolateral ST Depression

Leads I, aVL, V2, V3, V4, V5, and V6 are examined for ST depression. ST depression of more than 0.20 mV in these leads produces one of two statements, each of borderline severity. One suggests possible subendocardial injury; the other is in association with LVH and suggests that the ST changes are probably secondary to LVH.

Anterior T Wave Changes

Leads V1, V2, V3, V4, and V5 are examined for negative T waves. As negative values increase from 0.01 mV to more than 1.0 mV, the statements change from "nonspecific" T wave changes with a severity of Normal, to "anterior ischemia" with a severity of Borderline.

Inferior T Wave Changes

Leads II, III, and aVF are examined for negative T wave values. As negative values increase from 0.10 mV to more than 1.0 mV, the statements change from "Nonspecific T wave changes" with a severity of Borderline, to "Consider Inferior Ischemia" with a severity of Abnormal.

Anterolateral T Wave Changes

Leads I, aVL, V2, V3, V4, V5, and V6 are examined for T wave values. Positive values more than 1.0 mV indicate a probably normal T wave variant. Negative values call attention to the possibility of ischemia, with increasing severity codes as the negative values increase from 0.01 mV to more than 1.0 mV. Statements range from those referring to "Nonspecific T wave changes" with a severity of Borderline to "Consider Anterolateral Ischemia" with a severity of Abnormal.

Anatomical Diagnoses

The likelihood of various congenital cardiac conditions is suggested on the basis of varying combinations of atrial enlargement, ventricular hypertrophy, conduction patterns, axis determinations, and QRS morphological features.

Severity

This is the final module of the ECL program where the overall severity for the entire ECG is determined based on the severity of the statements which have been selected for the report. Each statement which appears on the ECG report carries one of the following severities:

NO – Normal
ON – Otherwise Normal
BO – Borderline
AB – Abnormal
DE – Defective
NS – No severity assigned

The severity that is assigned to the ECG interpretive report as a whole is generally the same as the most severe statement in the report. The severity may be advanced one level from Otherwise Normal to Borderline or from Borderline to Abnormal if three or more statements on the report have the lesser severity.

7

Reading the Printed Report

This chapter describes the printed reports produced on the HP interpretive cardiograph. There are three types of clinical reports that the cardiograph can print:

Interpretive Report This report can include patient information, a ten-second ECG waveform, and a set of standard waveform measurements and interpretive statements.

Extended Measurements Report This report, available on some models, shows all the waveform measurements the HP interpretive cardiograph makes on an ECG, including morphology and rhythm measurements. These measurements are used to generate the interpretive statements printed on the Auto report.

Manual Report The HP interpretive cardiograph can also print a continuous ECG waveform in a variety of formats.

Auto Interpretive Reports

Interpretive reports show up to six blocks of information, as shown below. The operator can configure the HP interpretive cardiograph so it does not prompt for (and therefore does not print) any patient information except patient ID. The operator can also configure the cardiograph to include or omit various combinations of the basic measurements, the interpretive statements and the reasons statements. Note that your PageWriter may or may not have all of these capabilities.

Insert artwork here.

Figure 7-1. A Typical Interpretive Report.

A. Patient ID Information
B. Basic Measurements
C. Interpretive Information
D. Calibration Pulse
E. Rhythm Strip
F. Settings

Patient Information

This information is entered (or updated) by the technician when the ECG is taken. A complete listing of patient information codes is listed in Appendix B, **Patient ID Code Tables.**

Some patient information appears to the right of the interpretive information. This information can be changed when configuring the cardiograph. It includes the following information:

User A Label	Label such as "Smoker?" or "Temp?" that appears in ID entry process. Limited to eight characters.
User B Label	Label such as "Smoker?" or "Temp?" that appears in ID entry process. Limited to eight characters.
Requested by	This field displays the name of the physician who requested the report. Limited to 16 characters.
Edited	This memo prints if the patient ID information has been edited since it was first entered.

Basic Measurements

This block gives standard interval and duration measurements in milliseconds, and limb lead axis measurements in degrees. These are representative values for the dominant beat pattern in the ECG. For more information on how representative measurements are derived, refer to "How the HP Interpretive Cardiograph Measures ECGs" in Chapter 4.

Table 7-1. Basic Measurements

Item	Description	Units
RATE	Heart rate	beats per minute
PR	PR interval	milliseconds
QRSD	QRS duration	milliseconds
QT	QT interval	milliseconds
QTc	QT interval corrected for rate	milliseconds
P	Frontal P axis	degrees
QRS	Frontal mean QRS axis	degrees
T	Frontal T axis	degrees

Interpretive Information

This block contains:

The interpretive statements which may be accompanied by,

"Reasons" statements summarizing the conditions that produced each interpretive statement.

This block can also include the following types of technical information:

- **Calibration statements** indicating the scaling of the ECG trace. For example:

  ```
  All leads HALF standard calibration.
  All channels = 5 mm/mV.
  ```

- **Quality statements** indicating signal problems that occurred during the recording. For example:

  ```
  Artifact in lead(s) I  III  aVL
  ```

- **Severity statement** indicating the ECG's classification. The severity that is assigned to the ECG interpretive report is generally the same as the most severe statement in the report. This is always the last statement in this block. The Criteria define five severity levels. In order of severity, they are:

  Normal ECG
  Otherwise Normal ECG
  Borderline ECG
  Abnormal ECG
  Defective ECG

Calibration Pulse

This is the rectangular waveform shown in each line of ECG trace. It shows how much the cardiograph deflected the trace in response to a 1 mV calibration pulse applied to the acquisition circuitry.

The shape of the calibration pulse reflects the scaling of the trace. (Set with the ECG Size or the F5 keys depending on your cardiograph.). If the calibration pulse is square, the chest leads and limb leads were recorded at the same scale. If the calibration pulse is stepped, the cardiograph recorded the chest leads at half the scale of the limb leads. The following table shows how the calibration pulse indicates ECG sensitivity.

Table 7-2. Calibration Signals

	V Leads/ECG Size	
ECG Size mm/mV	**Full**	**Half**
5		
10		
20		

Rhythm Strip

The HP interpretive cardiograph can print ten seconds of one lead or of three leads at the bottom of the Auto report. This additional trace is a rhythm strip. Rhythm strips show the same ten seconds of ECG data as in the Auto report.

Settings

Information about the settings at which the ECG was taken is listed at the bottom of the Auto report. Note that your PageWriter cardiograph may not have all these settings available.

LOC	This label includes a location code and a cart number.
Speed:	Indicates the speed at which the ECG was printed. Auto reports can be printed at 25 mm/sec or 50 mm/sec.
Limb:	Limb lead sensitivity setting. Can be 5, 10, or 20 mm/mV.
Chest:	Chest lead sensitivity setting. Can be 2.5, 5, 10, or 20 mm/mV.
Filter box	Indicates which filters were active when the ECG was recorded.
	F Artifact filter.
	W Baseline wander filter.
	60 ∿ AC filter
	0.5–40 Hz Auto frequency filters
Faulty Electrode	Leads off indication.
HP708	This is the measurements program (7) and criteria (08) versions used by the cardiograph.
00016	This is the sequence number, which indicates the number of ECGs taken as of the current report since the software was last installed.

Auto Report Formats

The ECG trace can be printed in any of the following formats.

Insert artwork here.

Figure 7-2. An Auto 3x4 Report. (3x4)

Insert artwork here.

Figure 7-3. An Auto 3x4 Report with a Rhythm Strip. (3x4, 1R)

Insert artwork here.

Figure 7-4. An Auto 3x4 Report with 3 Rhythm Strips. (3x4, 3R)

Insert artwork here.

Figure 7-5. An Auto 6x2 Report. (6x2)

Extended Measurements Report

The Extended Measurements report gives a complete listing of the measurements the cardiograph made to derive the interpretation of an ECG. This report is especially useful if you want to examine the logic of the given interpretation. Refer to your cardiograph's *User's Reference Guide* for information on printing this report. Note that your PageWriter cardiograph may not have this capability.

An explanation of each field of the report is in Appendix C, **The Extended Measurements Report.**

Insert artwork here.

Figure 7-6. An Extended Measurements Report (Morphology).

Insert artwork here.

Figure 7-7. An Extended Measurements Report (Rhythm).

Manual Reports

When the operator starts a Manual report, the HP interpretive cardiograph prints the ECG until the operator stops the recording.

Manual reports show up to three types of information:

- Patient information
- ECG trace
- Settings information

Manual ECGs include the same patient information as on Auto ECGs. This information appears above the waveform. Manual reports are not analyzed, so they do not provide measurement information or interpretive statements. The calibration pulse appears at the beginning of the ECG trace.

Cardiograph Settings

The cardiograph settings appear above the waveforms on Manual reports. Note that your PageWriter cardiograph may not have all these settings available.

LOC	This label is at the bottom of the Manual report page. It includes the location code and cart number.
Speed:	Indicates the speed at which the ECG was printed. Manual reports can be printed at 5, 10, 25, or 50 mm/sec.
Limb:	Limb lead sensitivity. Can be 5, 10, or 20 mm/mV.
Chest:	Chest lead sensitivity. Can be 2.5, 5, 10, or 20 mm/mV.
Filter box	Indicates which filters were active when the ECG was recorded. **F** Artifact filter. **W** Baseline wander filter. **60** $\sim$ AC filter **0.5–40 Hz** Manual frequency filters
Faulty Electrode	Leads off indication.
00019	This is the sequence number, which indicates the number of ECGs taken as of the current report since the software was last installed.

Manual Report Formats

Manual reports can have any combination of three, six, or 12 leads. These Manual report formats are shown in the following figures:

Insert artwork here.

Figure 7-8. A Manual 3-Lead Format.

Insert artwork here.

Figure 7-9. A Manual 6-Lead Format.

Insert artwork here.

Figure 7-10. A Manual 12-Lead Format.

8

Managing Your ECGs

Besides producing local hardcopy reports, many HP interpretive cardiographs can be linked to Hewlett-Packard ECG Management Systems. On some PageWriter models, ECGs may be stored to flexible disk for permanent archival, storage or transmission. You may want to send your ECGs to another site for clinical review, long-term storage and retrieval, or for management. Figure 8-1 shows the ECG management process. (Note that Operator Feedback is not available on some PageWriter models.)

The method of transfer can vary, depending on your requirements and the capabilities of your cardiograph:

- storage on flexible disk: can be used by the HP interpretive cardiograph for subsequent retrieval and for batch ECG transmission
- local transmission through direct connect cable.
- remote transmission via telephone modem.

ECGs can be received by any of Hewlett-Packard's ECG Management Systems and WorkStations, or by some models of HP interpretive cardiographs. ECGs stored to flexible disk by non-interpretive PageWriter cardiographs can both be analyzed and transmitted in batch by a disk-equipped HP interpretive cardiograph.

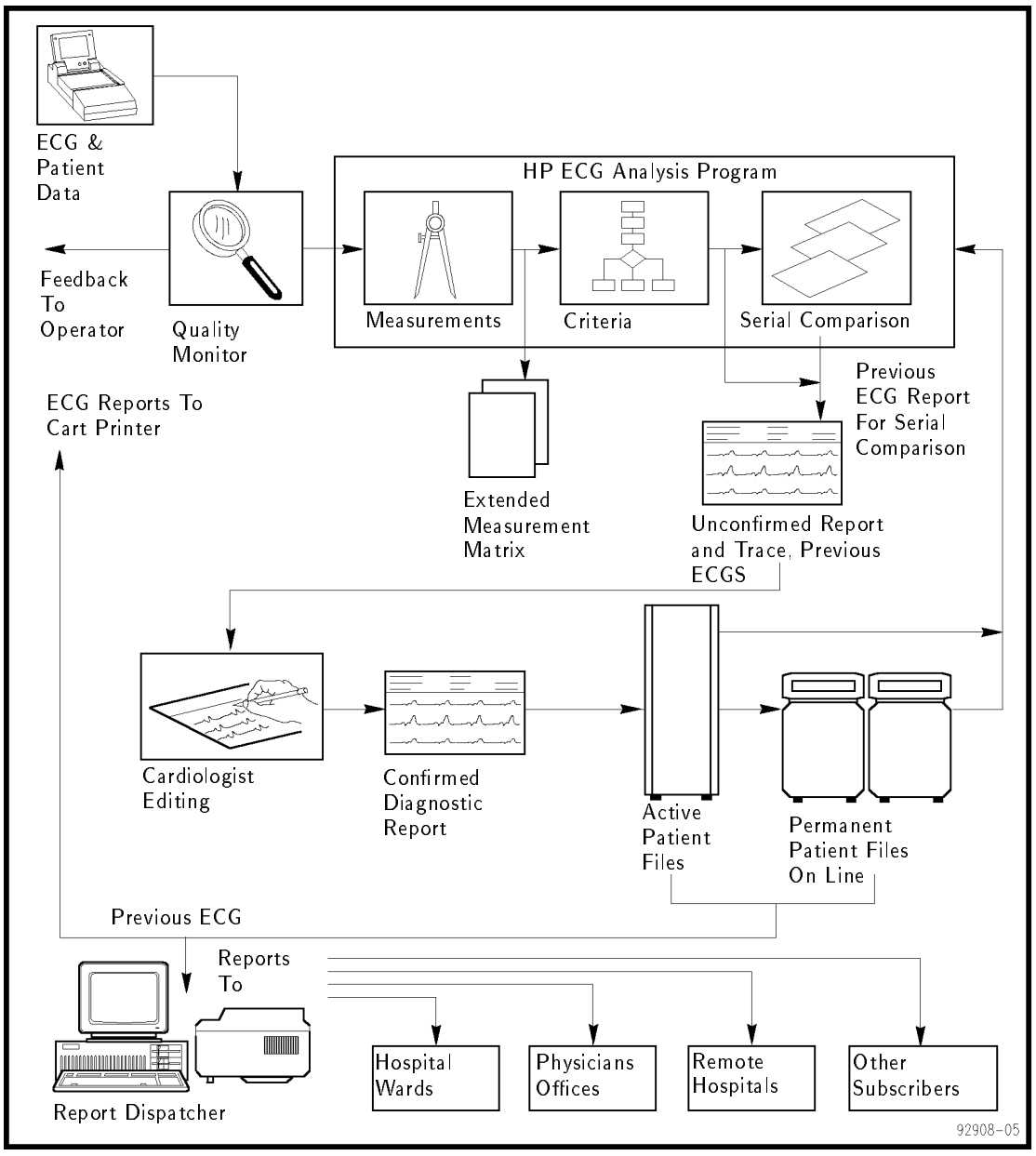

Figure 8-1. Managing ECGs.

PageWriter Communications

Many HP interpretive cardiographs incorporate a digital transmission scheme to provide flexibility and guarantee error-free ECG transmission. ECG storage space and telephone connect time are minimized by the use of non-distorting compression algorithms.

An important part of the transmission protocol is its error detection and handling capabilities. The lower level of the protocol packages each block of data with CRC (cyclic redundancy check) codes, and any detected error results in retransmission of data. If a block cannot be transmitted without error after numerous attempts have been made, the link is terminated and the operator is notified.

The upper level of the protocol supports an expandable command interpreter that allows the transmission of ECGs, analysis reports and measurement matrices from cardiograph to cardiograph, cardiograph to an ECG Management System, and ECG Management System to a cardiograph. For example, following ECG transmission from the patient's bedside, a physician can receive a previous ECG from the system for an immediate comparison.

ECG Management Systems

When an ECG is received and stored by a Hewlett-Packard ECG Management System several functions can be initiated.

- reports can be automatically generated. When, where, and in which format are all under your control.
- a previous ECG (or ECGs) can be retrieved and appended to the current report for immediate review.
- ECGs can be edited. Using Hewlett-Packard's ECL statement library or using free-form text, the ECG can be modified with overreading comments.
- Automatic dispatch. The final report, with any necessary comments or corrections can be returned to its originating location, and/or to other sites sharing the ECG Management Network.
- ECGs can be archived for long-term storage. The system can archive many thousands of ECGs, automating a very labor intensive process.
- ECGs can be used for clinical research.

Clinical Rewards

On a practical level, ECG management will assist the cardiologist or physician in the recovery of ECG information. Those who use ECG Management systems have found that automating their ECG filing system significantly reduces the number of misplaced ECGs. This, combined with the greater speed and consistency associated with computerized record management, has resulted in a 3% to 15% improvement in recaptured billings for these institutions.

Automated ECG departments can further help the cardiologist when overreading ECGs. Our experience has shown that a doctor can overread up to three times more quickly with computerization. Ultimately this means more time with the patient.

There are benefits to be gained in the areas of clinical research. Having thousands of ECGs on line and available for study on very specific parameters (How many male patients over 60 years have first degree AV block?) enables drug trials, therapeutic care and teaching improvements to be realized very easily. Such a statistically significant population has encouraged many of the largest drug companies in the world to employ Hewlett-Packard systems in their research. Most of the information that appears on the final report may be used as a search field. Furthermore, searches may be made on search result files, thus allowing multiple detailed secondary levels of examination.

Current Trends

Worldwide, health-care facilities are under mounting governmental pressure to reduce costs and manage themselves more efficiently. As would be expected, they are relying heavily on information systems to assist them in this challenge. In the cardiology department, staff productivity related to the management and storage of test data from high-volume tasks such as ECG processing are especially improved.

Networking these products offers a unique solution to the institution looking to manage their expanding ECG volume effectively, and to respond to the overreading demands of smaller surrounding institutions. Transaction logging prevents loss of ECGs.

Previously, the high cost of large centralized ECG Management systems limited them to only the largest hospitals. However, the decreasing cost of technology will now allow vendors to offer solutions to all institutions, regardless of size. As these solutions develop, Hewlett-Packard customers can continue to expect a high standard of compatibility. This means that the many years of ECGs stored on your current system will not be lost in a transition to our next generation products.

A

Questions and Answers

How accurate is the cardiograph's interpretation?
The accuracy you perceive will be determined mainly by your style of reading ECGs. The typical overreading physician will agree with approximately 80% to 85% of the positive findings stated in the interpretation. A normal ECG will be correctly interpreted approximately 98% of the time. Though false positive errors (indicating features that do not exist) will intentionally outnumber false negative errors (missing features that do exist), both will occur, thus the necessity for overreading by a qualified physician of any computer-interpreted ECG. The computer interpretation indicates features of the ECG—it does not produce a definitive diagnosis.

Why are different interpretations frequently made of ECGs taken on the same patient only a short time apart, or for repeat tests on the same ECG simulator?
There are always small variations in the actual ECG characteristics from beat to beat. There are also variations in artifacts and noise in the signal. These variations, though possibly very small and not readily visible, result in measurement variations that either meet or do not meet threshold values of significance to the interpretive criteria. This can result in differing interpretive statements.

ECG simulators should not be used to test the cardiograph's interpretation. Simulators generally produce waveforms that emulate how certain ECG patterns *look* but which do not represent the full information content of genuine ECGs. In addition, simulators frequently store the waveform for only one lead and reconstruct all other leads from it. Because the cardiograph's interpretation uses information from multiple leads, such fabricated information may confuse it. A simulated ECG is not an adequate substitute for a human ECG.

Why do my axis value determinations differ from those calculated by the cardiograph?
A person calculating axis values primarily looks at the amplitude (voltage) of the waveform components. The cardiograph computes the area under the waveform components to arrive at more accurate axis values.

Is the rhythm strip portion of an Auto ECG interpreted?
Analysis is done only on the basis of measurements made on each of the four 3-lead groups in the 12-lead portion of the report.

What factors determine how many ECGs can be stored on a single disk on an HP interpretive cardiograph?
Information is stored on disks in a compressed form. Artifacts and high heart rates require more space for the compressed data. Consequently, if many noisy or rapid rate ECGs are involved, the number of ECGs stored on a single disk is reduced. Storage of rhythm strips also requires disk space and will reduce the number of ECGs stored.

In addition, if the ECGs are stored at 500 samples per second, the number of ECGs stored on each disk will be significantly decreased. Storage at 500 samples per second is for a full ten seconds for each of the 16 leads while storage at 250 samples per second is for only the four, 3-lead groups seen in the Auto 12-lead report plus rhythm strips, if present. Most users store ECGs at 250 samples per second.

Why is sinus bradycardia defined as a rate less than 50 beats per minute instead of less than 60?
Although there are different definitions of bradycardia, Hewlett-Packard uses the definition recommended by the American College of Cardiology's Task Force on Standardization of Terminology and Interpretation as published in the *American Journal of Cardiology*, January l978.

Can changes be made in the interpretive criteria?
With adjustable criteria physicians can refine the analysis algorithm's performance to their standards. Adjustable criteria sets allow individual institutions to modify the program's criteria to meet local standards, and to more closely match local population characteristics. Also, adjustable criteria is more than simply changing the program's terminology to match local nomenclature.

In the Hewlett-Packard implementation, a clinician can:

- change the thresholds that are used by the program in making interpretive statements;
- change severity classifications of a particular interpretive statement, and
- upgrade or delete criteria;
- add new criteria to address specific research or clinical studies.

Obviously, adjustable output introduces a risk that a clinician may alter criteria to a less accepted, or invalid, version. In essence this corrupts the performance of the system. Therefore, before final implementation, Hewlett-Packard's 5600C ECG Management system supports facilities that allow complete testing of the modifications. A thorough examination can be performed on the new criteria's accuracy by reanalyzing old ECGs with the new criteria, and comparing the interpretation against known output.

Can interpretation be turned off?
Yes. Some cardiographs can be configured to print interpretation (with or without reasons) and/or measurements, or no analysis at all.

What are the advantages of the 0.15 Hz and 150 Hz filters?
The 0.15 Hz filter meets all of the standards for low frequency ECG signals and provides better baseline wander removal than a 0.05 Hz filter. The 150 Hz filter permits higher frequency ECG signals to be visualized in the tracing as well as to be available for computerized analysis.

What does the (Filter) key do?
This key activates the baseline wander filter or the artifact filter or both as selected by the user in the configuration process. These filters reduce the baseline wander or the muscle artifact as printed on the Auto 12-lead ECG tracing. The artifact filter does not affect the data that is used for analysis. (Note that your cardiograph may not have all of these capabilities.)

Can Cabrera reports be presented?
Yes, on some PageWriter models. If available, the cardiograph can be configured to print the limb leads in the Cabrera order (aVL, I, −aVR, II, aVF, III) instead of the more traditional order (I, II, III, aVR, aVL, aVF).

Cabrera order makes it easier to visualize waveform progression in the frontal plane.

Insert artwork here.

Figure A-1. A Cabrera Report. (6x2)

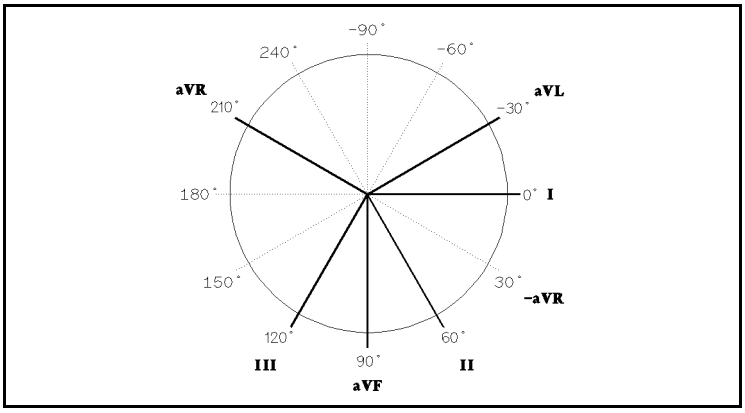

Figure A-2. Frontal Plane Lead Axes.

What is "preacquisition"?
Whenever the cardiograph is turned on and the leads are connected to the patient it begins acquiring the incoming ECG signals in an internal buffer. The most recent ten seconds are kept in memory for immediate use in analyzing and printing the ECG when the Auto key is pressed. Because Manual ECGs are used when a real-time report is desired, preacquisition is not used for Manual ECGs.

How can I use the preview screen feature?
The preview screen tracing sweeps to show the immediate ECG signal. It retains the preceding six seconds on the screen for viewing. This gives the operator an opportunity to evaluate the quality of the signal from each of the 12 leads before beginning either an Auto or a Manual ECG. (Note your cardiograph may function differently.)

What patient ID information affects both Adult and Pediatric interpretations?
Age, Dx, and Rx entries are factors considered by both criteria. Sex, height and weight are factors considered in only the adult criteria. Blood pressure and race also can be accessed by the program but are not used by either of the standard HP programs. The cardiograph will use pediatric criteria for patients less than 16 years old. The adult criteria will be used for all other patients, including those for whom no age is entered. (Rx codes, Dx codes and race codes may not be available on some PageWriter models.)

What are the four blank plugs on the PageWriter XL patient module used for?
These plugs cover receptacles for four additional leads. The cardiograph can be configured to use these leads in any one of three different ways:

Pediatric leads V4R, V3R and V7
Frank leads X, Y, and Z
Custom unipolar leads for research purposes

In all of these uses, the leads produce waveform tracings but are never measured or used for interpretation.

What is the relationship between the group measurements in the Rhythm Analysis section and the lead measurements in the Morphology Analysis section of the Extended Measurements report? How do these measurements relate to the global measurements listed with the axis measurements on the Extended Measurements report, and in the Basic Measurements section on the Interpretive report?
For the group measurements in the Rhythm Analysis section, all beats are classified into one of five groups based on rate and morphology parameters. Each group is representative of beats with similar R-R intervals, durations and shapes, except that all paced beats are grouped together, regardless of other parameters. Group 1 represents the type of beat that is most normal or predominant and other beat types are classified into groups 2 through 5. The representative group measurements are calculated by averaging the measurements for all the beats in the group. (Note that your PageWriter may not have these capabilities.)

The lead measurements in the Morphology Analysis section are derived from all the measured beats in each lead and are representative of the dominant waveform present in the lead. For each of the 12 leads, all the beats from the predominant beat group are averaged to form the lead measurements. Measurements will not be made for paced beats unless all beats are determined to be paced.

The Basic Measurements displayed on the Interpretive report and on the Extended Measurements report are global measurements representative of the dominant waveforms throughout the entire ECG. They are calculated from the individual lead measurements in the Morphology Analysis section of the Extended Measurements report using weighted averages. The rate reported in the Basic Measurements is the global mean ventricular rate unless the ECG criteria program determines that one of the group mean ventricular rates is more representative of the underlying rhythm of the ECG.

B

Patient ID Code Tables

Table B-1 shows the fields in the sequence that they may appear during patient ID entry. The patient ID number is the only field that must be filled in for storage of an Auto ECG. Refer to your cardiograph's *User's Reference Guide* for further information on patient ID. (Note that your cardiograph may have storage capabilities.)

Note

Some PageWriter cardiograph models may be configured so that patient ID is automatically requested each time you start an ECG. If you do not want to enter patient ID on a PageWriter so configured, press Auto or Manual again to override the request for patient ID.

Table B-1. Patient ID Fields

Prompt	Comments	Entry	# of char.
Patient ID?*	Type the patient ID number.	Alphanumeric	16
Name?	Type the patient name.	Alphanumeric	30
Age(years, months, weeks, days, hours, year of birth)?	Choose age designation. Type the age.	Numeric	4
Sex?	Choose Male or Female.		
Height (in. or cm)?	Type the height.	Numeric	3
Weight (lb or kg)?	Type the weight.	Numeric	3
Systolic BP?*	Type the systolic blood pressure.	Numeric	3
Diastolic BP?*	Type the diastolic blood pressure.	Numeric	3
Race? (1–9)*	Type the race code. See Table B-3.	Numeric	1
Rx?*	Type the medication codes. See Table B-2.	Alphanumeric	3
Dx?*	Type the diagnosis codes. See Table B-2.	Alphanumeric	3
Criteria Version?*	Type the criteria version ID.	Alphanumeric	2
Operator?	Type the cardiograph operator's name or number.	Alphanumeric	4
Department?	Type the department name or number where the ECG is recorded.	Alphanumeric	4
Room?	Type the patient's room name or number.	Alphanumeric	8
Requested by?	Type the name or number of the person who requested the ECG.	Alphanumeric	16
User A?/User B?*	User-defined labels. Create and enable these in global configuration.	Alphanumeric	16
Stat ECG?*	This code is relevant when sending ECGs to an HP ECG Management System.	Yes or No	1

* Refer to the *User's Guide* for the specific fields available for your cardiograph.

Table B-2. Medication and Diagnosis Codes

Rx Statement	Code	Rx Statement	Code	Dx Statement	Code
Antiarrythmia drug	a	*Beta blocker drug*	6	*Arteriosclerotic HD*	1
. Amiodarone	e	. Propranolol	p	. Angina pectoris	a
. Dilantin	d	*Calcium blocker*	c	. Myocardial infarction	i
. Lidocaine	1	*Coronary artery dilator*	u	. Post op bypass	b
. Procainamide	2	. Isosorbide	i	*Artificial pacemaker*	2
. Quinidine	3	. Nitroglycerin	n	*Cardiomyopathy*	3
Anticoagulant drug	4	*Digitalis*	7	*Congenital HD*	4
. Coumadin	w	*Diuretic drug*	8	. Congenital HD acyanotic	e
. Heparin	g	. Lasix	l	. Congenital HD cyanotic	d
. Streptokinase	s	. Thiazide	t	*Hypertensive HD*	5
Antihypertensive drug	5	*Psychoactive drug*	f	*Pulmonary disease*	6
. Captopril	j	. Potassium chloride	9	*Rheumatic HD*	7
. Clonidine	k	. Barbiturate	b	. Aortic valvular disease	8
. Hydralazine	h	. Phenothiazine	v	. Mitral valvular disease	9
. Reserpine	r	. Tricyclic antidepressant	x	. Combined valvular disease	c
Antihypotensive drug	o	*No known Rx*	z	*No known Dx*	z
Antiasthmatic drug	m				
. Aminophyline	y				
. Isuprel	q				

Note that some PageWriter models do not prompt for this information.

Table B-3. Race Codes

Race Statement	Code
Aleut or Eskimo	1
American Indian	2
Black	3
Hawaiian	4
Hispanic	5
Oriental	6
Pacific Islander	7
White	8
Other Race	9

Note that some PageWriter models do not prompt for this information.

Table B-4. Severity Codes

Severity	Code
Normal ECG	NO
Otherwise Normal ECG	ON
Borderline ECG	BO
Abnormal ECG	AB
Defective ECG	DE

C

The Extended Measurements Report

The two-part Extended Measurements report summarizes the morphology and rhythm characteristics for the individual leads and rhythm groups in the ECG. The HP ECG Analysis Program uses the Extended Measurements report information to generate interpretive statements. An Extended Measurements report is available for each ECG when it is recorded or later if the ECG is stored. Note that Extended Measurements report capabilities is available only on some PageWriter models.

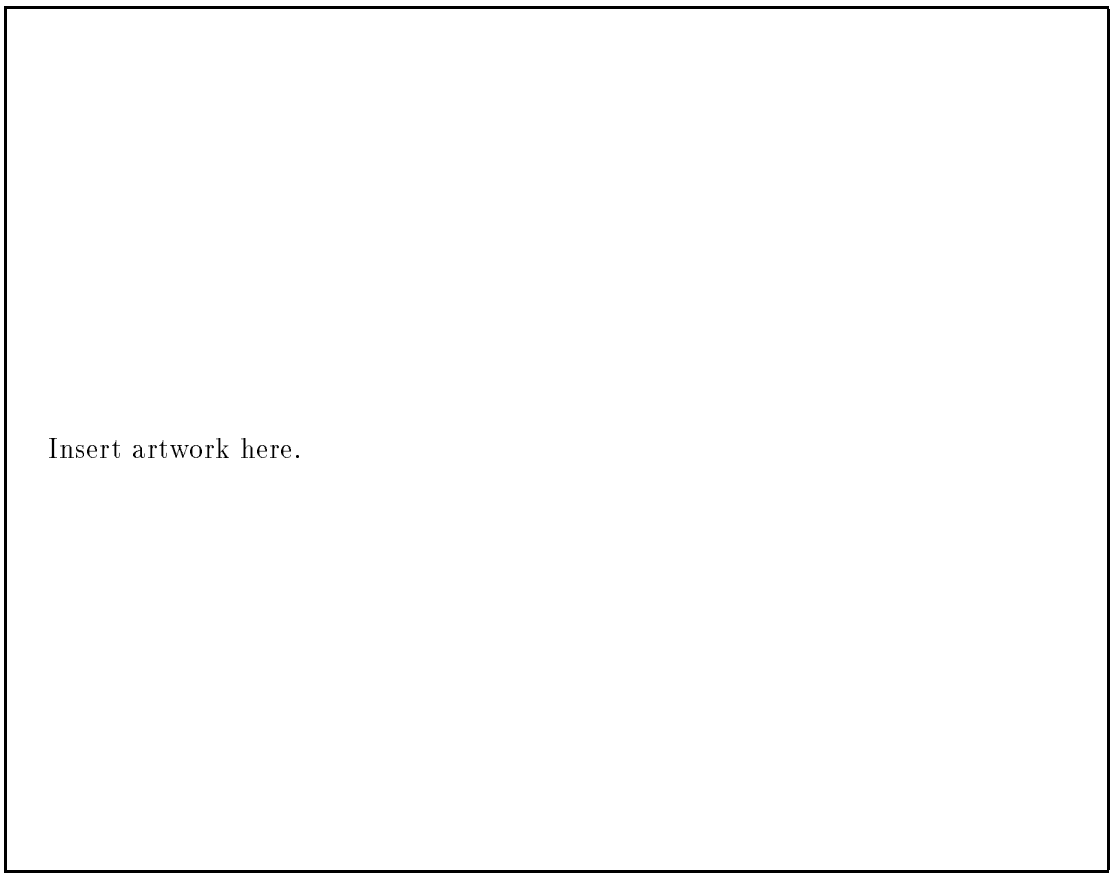

Figure C-1. An Extended Measurements Report. (Morphology)

Morphology Analysis

The following tables define the parameters in the order that they appear on the morphology analysis page of the extended measurements report.

Individual Lead Measurements

The following table lists every representative measurement in each lead. The parameters in the following tables are shown in Figure C-2.

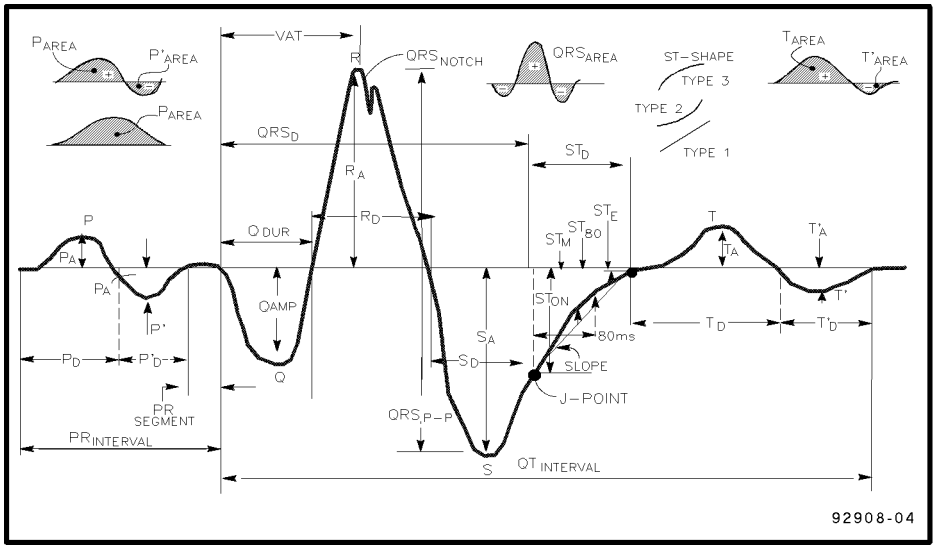

Figure C-2. ECG Morphology Measurements.

Individual Lead Measurements

Parameter	Units or Value	Description
P AMP	millivolts	P wave amplitude.
P DUR	milliseconds	P wave duration.
P AREA	Ashman units (40 ms x 0.1 mV)	P wave area for monophasic P waves or the area of the initial portion of a biphasic P wave.
P NOTCH	Yes or No	Indicates the presence or absence of a notch in the P wave.
P′ AMP	millivolts	P′ wave amplitude.
P′ DUR	milliseconds	P′ wave duration.
P′ AREA	Ashman units (40 ms x 0.1 mV)	Area of the terminal portion of a biphasic P wave.
Q AMP	millivolts	Q wave amplitude.
Q DUR	milliseconds	Q wave duration.
R AMP	millivolts	R wave amplitude.
R DUR	milliseconds	R wave duration.
S AMP	millivolts	S wave amplitude.
S DUR	milliseconds	S wave duration.

Individual Lead Measurements (continued)

Parameter	Units or Value	Description
R′ AMP	millivolts	R′ wave amplitude.
R′ DUR	milliseconds	R′ wave duration.
S′ AMP	millivolts	S′ wave amplitude.
S′ DUR	milliseconds	S′ wave duration.
QRSAREA	Ashman units (40 ms x 0.1 mV)	The area of the QRS complex.
QRSNTCH	+ or −	Indicates a notch in the QRS complex. A + indicates a notch or slur in the R or R′ wave. A − indicates a notch or slur in the Q, S or S′ wave.
DELTA	Yes or No	Indicates the presence or absence of pronounced delta waves preceding QRS complexes.
ST ON	millivolts	Elevation or depression at the onset (J point) of the ST segment.
ST MID	millivolts	Elevation or depression at the midpoint of the ST segment.
ST 80ms	millivolts	Elevation or depression of the ST segment 80 ms after the end of the QRS complex (J point).
ST END	millivolts	Elevation or depression at the end of the ST segment.
ST DUR	milliseconds	ST segment duration.
STSLOPE	degrees	ST segment slope. Slope is measured in degrees and can range from 0 to ±90 degrees.
STSHAPE	−, V, or ^	The ST segment shape: − = Straight V = Concave upward ^ = Concave downward
T AMP	millivolts	T wave amplitude.
T DUR	milliseconds	T wave duration.
T AREA	Ashman units (40 ms x 0.1 mV)	T wave area for monophasic T waves or the area of the initial portion of a biphasic T wave.

Individual Lead Measurements (continued)

Parameter	Units or Value	Description
T NOTCH	Yes or No	Indicates the presence or absence of a notch in the T wave.
T′ AMP	millivolts	T′ wave amplitude.
T′ DUR	milliseconds	T′ wave duration.
T′ AREA	Ashman units (40 ms x 0.1 mV)	Area of the terminal portion of a biphasic T wave.
PR INT	milliseconds	Interval from the onset of the P wave to the onset of the QRS complex.
PR SEG	milliseconds	Interval from the end of the P wave to the onset of the QRS complex.
V.A.T.	milliseconds	Ventricular Activation Time: the interval from the onset of the QRS complex to the latest positive peak in the complex, or the latest substantial notch on the latest peak, whichever is later.
QRS PPK	millivolts	Peak-to-peak QRS complex amplitude.
QRS DUR	milliseconds	QRS complex duration, measured from its onset to the ST segment onset (J point).
QT INT	milliseconds	Interval from the onset of the QRS complex to the end of the T wave.
GROUP	1 (or 2–5)	Indicates the rhythm group used to derive the representative measurements for each lead. Will be Group 1 unless no Group 1 beats were detected during the analysis interval for this lead.

Individual Lead Measurements (continued)

Parameter	Units or Value	Description
QUALITY	N/A	Each character indicates a type of noise present in the lead: **D** = Baseline wander indicator. The onsets of two successive QRS complexes differ by more than 1/3 the calibration value. **T** = Artifact, most likely muscle tremor. Occurs when more than 16 up-and-down strokes exceeding 1 mm in amplitude are detected within 1 second. **W** = Steady baseline drift exceeding 10 mm/sec. **A** = Power line (AC) noise. **M** = Missing lead.
NOISE	N/A	Indicates the severity of artifact reflected in the signal data: blank = Light noise 1 = Moderate noise 2 = Marked noise 3 = Severe noise

An Ashman unit is the area of 1 square millimeter at normal speed (25 mm/sec) and normal sensitivity (10 mm/mV). An Ashman unit equals 40 ms x 0.1 mV.

Cal Factors

The factor by which the ECG trace differs from standard scaling (10 mm/mV). Standard scaling is indicated by a CAL factor of 1.00.

Cal Factors

Parameter	Units or Value	Description
Cal Assumed	Appears only when true	The cal pulses were measured to be of non-standard amplitude or shape. This may indicate a cardiograph malfunction.
Paced Beats Measured	Appears only when true	All beats are paced and measurements are for paced beats.
QRS-like Artifact Detected	Appears only when true	Spike-like artifact was detected that may have caused measurement error.
Cart 1/2V	Appears only when true	Cart was set to print chest leads at half the scale of the limb leads.
Computer 1/2V	Appears only when true	The ECG Management System automatically scaled the chest leads at half the scale of the limb leads. This message can only appear on ECGs printed by the ECG Management System.

Frontal/Horizontal

The following table lists frontal plane and horizontal plane axis parameters and the global measurements representative of the entire ECG.

Frontal/Horizontal

Parameter	Units or Value	Description
P	degrees	P wave axis.
I:40	degrees	Initial 40 ms QRS complex axis.
QRS	degrees	Mean QRS complex axis.
T:40	degrees	Terminal 40 ms QRS complex axis.
ST	degrees	ST segment axis.
T	degrees	T wave axis.
Mean Ventr. Rate	beats per minute	Representative ventricular rate for the entire ECG.
Mean PR Int.	milliseconds	Representative PR interval for the entire ECG.
Mean PR Seg.	milliseconds	Representative PR segment for the entire ECG.
Mean QRS Dur.	milliseconds	Representative QRS duration for the entire ECG.
Mean QT Int.	milliseconds	Representative QT interval for the entire ECG.
Mean QTc	milliseconds	Representative QT interval adjusted to a heart rate of 60 beats/minute

Analysis Statement Codes

These codes are the criteria codes for the interpretive statements printed on the Interpretive report.

Rhythm Analysis

Group Measurements

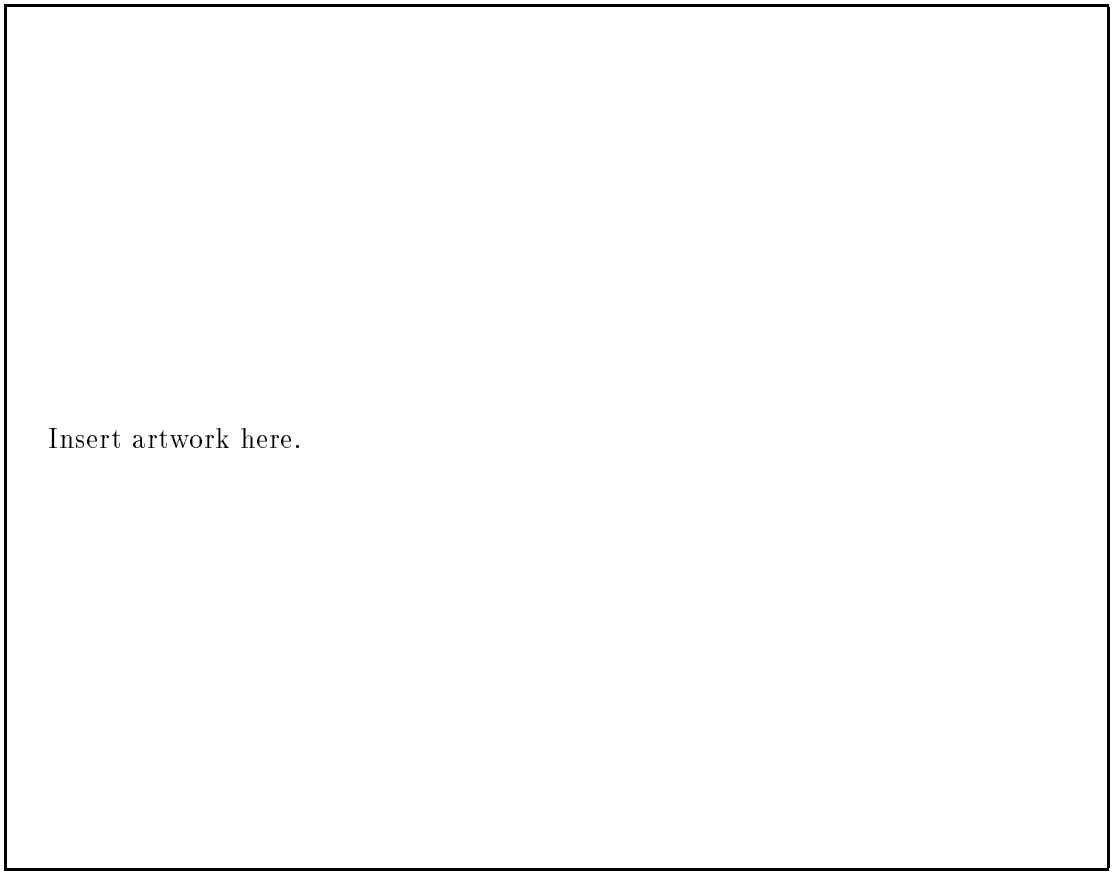

Figure C-3. An Extended Measurements Report. (Rhythm)

The following are parameters given for each rhythm group detected by the HP interpretive cardiograph during the analysis interval.

Group Measurements

Parameter	Units or Value	Description
Member Count	N/A	Number of beats in the rhythm group.
Member %	percentage	Percentage of the total number of beats represented by the rhythm group.
Longest Run	N/A	Longest contiguous run of beats in the rhythm group.
Mean QRS Duration	milliseconds	Average QRS duration in the rhythm group.
Low Ventr Rate	beats per minute	Lowest ventricular rate in the rhythm group.
Mean Ventr Rate	beats per minute	Average ventricular rate in the rhythm group.
High Ventr Rate	beats per minute	Highest ventricular rate in the rhythm group.
V-Rate Std.Dev.	N/A	Standard deviation of the ventricular rate in the rhythm group.
Mean RR Interval	milliseconds	Average interval between R waves in the rhythm group.
Mean Atrial Rate	beats per minute	Average atrial rate in the rhythm group.
A-Rate Std.Dev.	N/A	Standard deviation of the atrial rate in the rhythm group.
Avg. P Count	N/A	Average number of P waves per QRS complex in the rhythm group.

Group Measurements (continued)

Parameter	Units or Value	Description
# Not Avg P Beats	N/A	Number of QRS complexes in the rhythm group which do not have the average number of P waves per QRS complex.
Low PR Interval	milliseconds	Shortest PR interval in the rhythm group.
Mean PR Interval	milliseconds	Average PR interval in the rhythm group.
High PR Interval	milliseconds	Longest PR interval in the rhythm group.
PR Int. Std.Dev.	N/A	Standard deviation of the PR interval in the rhythm group.
Mean PR Segment	milliseconds	Average PR segment in the rhythm group.
Mean QT Interval	milliseconds	Average QT interval in the rhythm group.
Comp. Pause Count	N/A	Number of beats followed by a compensatory pause in the rhythm group.

Group Flags

The parameters in this part of the rhythm analysis indicate the presence or absence of various rhythm-related conditions in the rhythm groups identified.

Group Flags

Parameter	Units or Value	Description
Artificial Pace	Yes or No	Indicates that beats in the rhythm group are paced. All paced beats are grouped together.
Interpolated Beat	Yes or No	Indicates the rhythm group contains the only interpolated beats.
Sinus Arrest	Yes or No	Indicates a prolonged R-to-R interval. Set for the sinusarrest resumption group.
PR Progress Longer	Yes or No	Indicates the PR interval is getting progressively longer in the rhythm group.
Wenckebach	Yes or No	Indicates presence of the Wenckebach phenomenon in the rhythm group.
Bigeminy	Yes or No	Indicates presence of a bigeminy rhythm. Set for the group consisting of ectopic beats.
Trigeminy	Yes or No	Indicates presence of a trigeminy rhythm. Set for the group consisting of ectopic beats.
Aberrant Shape	Yes or No	Indicates that beats in the rhythm group are in the minority and are wider than other beats from the same lead(s).
Mult. P Test Done	Yes or No	Indicates that beats in the rhythm group were tested for multiple P waves.
QRS Measured	Yes or No	Indicates that QRS-related parameters were measured in the rhythm group.

Global Rhythm Parameters

The following parameters provide global information for beats in the ECG.

Global Rhythm Parameters

Parameter	Units or Value	Description
Atrial Rate	Beats per minute	The representative atrial rate for the analysis interval. This is not a simple arithmetic average.
Low Ventr Rate	Beats per minute	The lowest ventricular rate during the analysis interval.
Mean Ventr Rate	Beats per minute	The average ventricular rate during the analysis interval.
High Ventr Rate	Beats per minute	The highest ventricular rate during the analysis interval.
Flut-Fib Indicator	N/A	Indicates approximate number of flutter-like or coarse fibrillatory waves per lead.
Fixed Mult P Morph	Yes or No	Indicates that all P waves are of consistent morphology.

Global Rhythm Parameters (continued)

Parameter	Units or Value	Description
Mult P Test Valid	Yes or No	Indicates that the tests performed to detect multiple P waves produced consistent results.
Delta Wave Count	N/A	Number of QRS complexes with pronounced delta waves.
Delta Wave %	Percentage	Percent of total beats with pronounced delta waves.
Bigeminy Count	N/A	Total number of beats in a bigeminy pattern, whether or not they are contiguous.
Bigeminy String	N/A	Total number of beats in the longest continuous bigeminy pattern.
Trigeminy Count	N/A	Total number of beats in a trigeminy pattern, whether or not they are contiguous.
Trigeminy String	N/A	Total number of beats in the longest continuous trigeminy pattern.
Wenckebach Count	N/A	Total number of Wenckebach cycles. A Wenckebach cycle is a series of beats whose PR intervals grow progressively longer, culminating in an unusually long RR interval (a dropped beat).
Wenckebach String	N/A	The number of beats preceding the dropped beat.

Rhythm Grouping of Beats

The Rhythm Grouping of Beats is a number string which relates spatially to the beats in the ECG and shows the rhythm group number for each beat as determined by the Rhythm Analysis portion of the Analysis Program. Possible values are:

1, 2, 3, 4, or 5	Rhythm group number
0	Beat unclassifiable by program
— —	Lead switching interval
NO MEAS	Program unable to measure any beats in the lead set.

D

Understanding the M1754A Signal-Averaging Process

Introduction

This appendix contains information about how the M1754A SAECG (Signal-Averaged ECG) application performs signal-averaging to provide measurements used to detect late potentials. Signal averaging minimizes the level of noise in the ECG to expose the microvolt-sized signals that would normally be obscured, since noise and late potential activity are similar.

The M1754A SAECG application has the following features.

- bipolar, uncorrected, orthogonal XYZ lead system
- ability to move the matching and noise windows
- ability to display and choose the template beat and template position
- ability to adjust fiducial point
- real-time display of:
  - each new incoming beat
  - noise level
  - percent of accepted beats
- ability to end a signal-averaged study based on noise level, on beats, or on demand
- noisy beat rejection separate from template matching
- spectral filter
- measurement of individual filtered XYZ leads
- measurement of combined vector
- clear, concise report detailing the test results.

Note

The predictive accuracy of late potential systems can vary. This accuracy is largely dependent on the criteria used in defining a late potential as well as system signal processing (filters, etc.). We suggest that you determine appropriate criteria through methods described in the published literature.

The HP SAECG late potentials system has been designed to correlate as closely as possible to the Corazonix Predictor late potential system. Both the HP system and the Corazonix system comply with most of the AHA recommendations described in recent publications. Exercise caution when trying to correlate HP SAECG data to data from systems which do not conform to the AHA recommendations.

M1754A ECG Signal Averaging

The following sections describe how the M1754A SAECG acquires and processes ECG signals.

- Signal Acquisition
- Template Selection
- Averaging
- Filtering
- Measuring

Signal Acquisition

It is important to understand the following topics to get optimal signal-averaged studies.

- SAECG patient preparation technique
- orthogonal lead system
- SAECG signal path

SAECG Technique

Good SAECG technique is essential to ensure signal quality. Since signal-averaging is performed to remove noise from the ECG signal, it is beneficial to start with a relatively noise-free ECG signal. Careful skin preparation, a relaxed patient, and the use of silver/silver-chloride electrodes are necessary to ensure signal quality.

Lead System

The standard lead system for signal averaging is the uncorrected X, Y, Z orthogonal lead system. There are three bipolar leads (X, Y, Z) and a right leg ground electrode. SAECG results are lead dependent, so comparative studies must be acquired with the same lead system.

SAECG Signal Path

The ECG signal is digitized and conditioned in the SAECG patient module before the signal is averaged. Figure D-1 shows the path the ECG signal takes during the signal-averaging process.

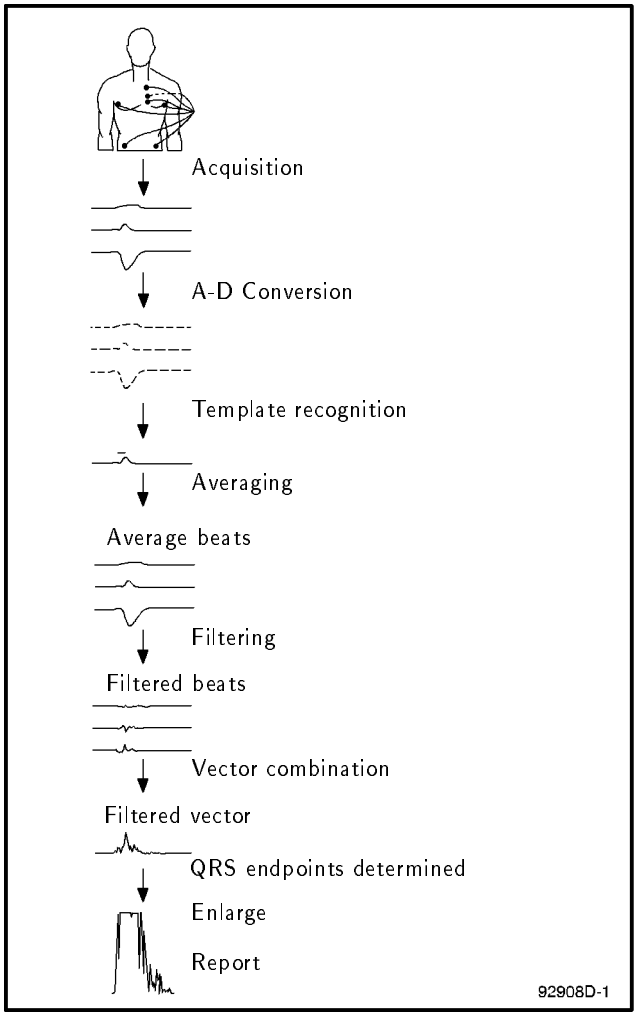

Figure D-1. The Signal-Averaging Process.

Signal Amplification. One of the first steps in recording high-resolution ECG signals is signal amplification. The SAECG patient module uses high-gain, low-noise preamplifiers to amplify the ECG while accurately preserving the content of the signal.

Signal Digitization. The patient module converts ECG signals into digital format using specialized software.

Analog-to-digital conversion takes place in the SAECG patient module at much higher sampling rates than in conventional ECG systems. The M1754A SAECG application acquires signals at 8000 samples per second on each channel. The 16-bit resolution allows a large dynamic range, and ensures no distortion of the large QRS signal as well as the much smaller late potential signals.

Signal Conditioning. There are four parts to the signal conditioning that occur in the cardiograph prior to signal averaging.

- low pass filtering to 300 Hz
- decimation to 2000 samples per second (to improve signal to noise ratio)
- leads created from individual electrode signals
- high pass filtering to 0.05 Hz

Template Selection

The template beat is selected automatically and is either confirmed or rejected by the user. This template beat is then used as a reference against which all incoming beats are matched. The matching window indicates the area of the template beat that is used to match all beats before they are included in the average. This matching window should be placed over the fastest moving part of the QRS complex and should include an inflection point on either the upstroke or the downstroke of the QRS.

The M1754A allows either the X, Y, or Z lead to be selected for the template lead. The lead shown on the preview screen when the template is accepted is the one that is used for the template lead. The matching window on this lead will be used to determine if a beat is accepted for averaging.

The template is initially set to the X lead. If the user changes to either the Y or Z lead, the matching window might need to be adjusted for optimum performance.

The noise value is derived from a combined measurement of the X, Y, and Z leads. The noise window should be placed in the S-T segment since it is a relatively smooth area except for noise.

Signal Averaging

Most noise on the ECG signal is random and can thus be eliminated by averaging multiple complexes. Typically from 100 to 500 beats are collected and averaged by the cardiograph. The recurring pattern of QRS and late potentials are preserved while the random pattern of noise is eliminated. The resulting signal-averaged waveform appears smooth and noise-free.

Before a beat is used in the average it is first precisely aligned with the template using the part of the beat in the matching window. Beats that are either excessively noisy or that have variant morphology are rejected. If the beat is acceptable, it is then added to the average.

As described above, beats that do not correlate (match) well enough are rejected. The threshold for this correlation can be changed in the M1754A configuration. A lower coefficient may be used to raise the acceptance rate in difficult studies, but it may yield a less than representative average.

The noise value is a measure of the RMS (Root Mean Square) voltage in the noise window. This window is placed by default on a relatively constant area of the ECG. The noise value provides a measure of quality of the signal average. The lower the noise, the better the quality of the average. High quality averages allow the critical points (QRS onset and offset) to be detected more accurately and thus yield more accurate measurements. Beats that raise the noise level are rejected. This allows the process to reach a high quality, low noise average in the minimum number of "good" beats.

When 10, 20, and 30 beat averages have been acquired, the template is replaced with the current average for matching. This improves the quality of the average by providing a more accurate template beat.

Averaging can be set to end when a level of noise is reached or a number of beats have occurred. If averaging is set to end when a level of noise is reached, the averaging is performed to the specified noise level, regardless of the number of beats or how long it takes to get to this noise level. If the cardiograph is set to average to the number of beats, the averaging is performed to the specified numbers of beats, regardless of noise levels. The user can also manually end the signal-average at any time.

It is recommended that the signal-average be set to end at a particular noise level. Averaging to a predetermined noise level ensures a reproducible signal-to-noise ratio between studies and ensures that the noise level is reduced enough to be able to see the low amplitude signals. This method allows measurements from different studies to be compared. The default value of 0.3 μV has been selected to provide high quality averages in a reasonable amount of time.

Beat Rejection

Not all beats should be used in a signal average. Beats that are not typical or are too noisy distort the average and its measurements, so it is important to properly handle these beats. A beat can be rejected for two reasons—not matching the template beat or being too noisy. Each new beat is aligned and its shape is compared to the template before being rejected or accepted. If accepted, the respective X, Y, and Z signals

are added to the average. How closely the beat must match (correlate to) the template is determined by the *correlation coefficient* in SAECG configuration set up. The default value is 0.99, but the setting can be changed so that the template beat does not have to be matched to new beats so closely.

The noise on a beat is measured by comparing the amount of noise in the average without the beat to the amount of noise in the average with the beat. If there is more noise in the average with the beat, then that noisy beat is rejected.

During averaging the far right side of the screen continuously lists three values:

- Number of beats
- Amount of noise
- Percentage of accepted beats

The percentage of accepted beats is determined by dividing the number of beats which are accepted for the average by the number of beats which pass the correlation test.

If beats are not accepted (no check mark) and the percent accepted beats goes down, beats are being rejected because they are noisy. The percentage accepted will not change if beats are being rejected for not matching the template within the correlation coefficient.

If many beats are being rejected for not matching the template, the correlation coefficient may need to be lower for that study.

Noise Reduction

Noise reduction is proportional to the square root of the number of beats averaged. This is represented in the noise reduction curve shown in Figure D-2. The minimum noise of a conventional ECG under ideal conditions is about 5 μV. With proper signal averaging, noise can be reduced to 0.3 μV after approximately 100 to 500 beats have been averaged.

It is important to start the signal-averaging test with relatively low noise since the noise is reduced more slowly later in the averaging. (Figure D-2) Note that the study begun with lower noise reaches the 0.3 μV level much sooner.

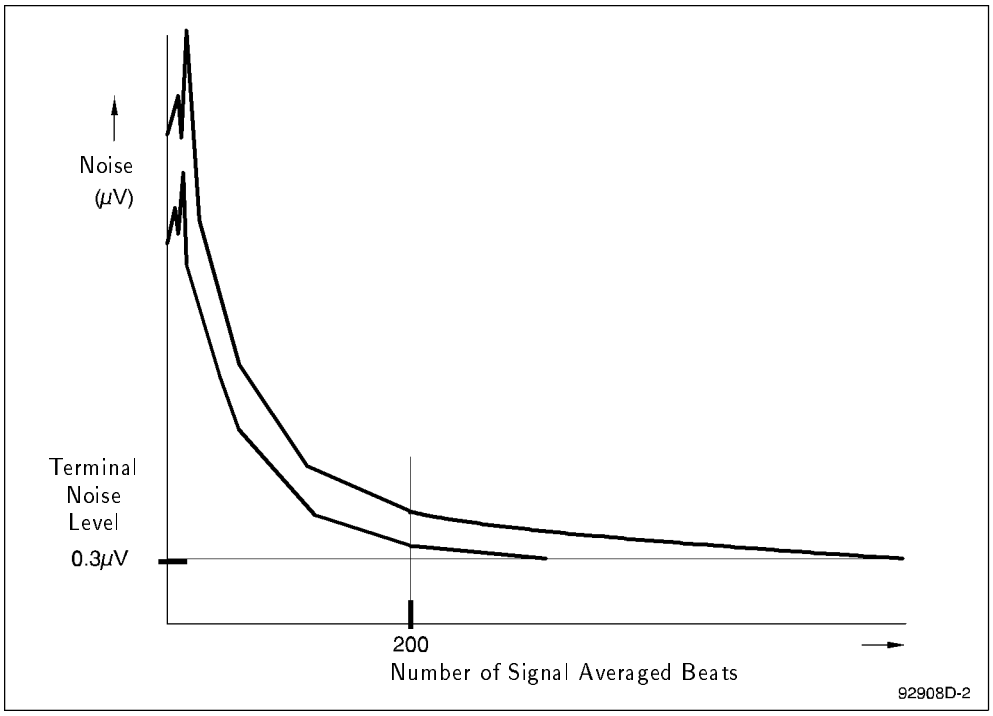

Figure D-2. The Noise Reduction Curve.

Filtering

The M1754A SAECG software uses a digital spectral filter which is a zero phase shift filter. An advantage of this type of filter is that it does not distort the QRS waveform. The spectral filter removes low frequency components of the signal.

High-pass filtering removes the low-frequency signals of the ST slope and the T-wave which can obscure the small late potential signals. This type of filtering preserves the remaining high frequency signals which include the late potential activity.

Since different researchers have used different high-pass cutoff frequencies in their analysis, the criteria used to determine the presence of late potentials have differed. The earliest studies in humans used a cutoff frequency of 25 Hz. More recently, researchers have used 40 Hz and even 80 Hz high-pass cutoff frequencies to document late potential activity. A 40 Hz cutoff frequently is the default frequency used in the M1754A, but it can be changed when setting up the application.

The filtered waveforms on the report (X, Y, Z, and composite) all have both high and low pass filtering applied so that measurements can be made. The band pass on these waveforms is the selected high-pass to 250 Hz. The unfiltered waveform band pass is 0.05 to 300 Hz.

Although individual filtered X, Y, and Z leads provide specific information on the presence of late potentials, the most common analysis procedure combines the X, Y, and Z leads into the vector magnitude waveform.

The advantage of this step is that the three orthogonal waveforms are combined for more simplified analysis. The vector magnitude waveform is calculated from the filtered leads by the equation:

$$\sqrt{X^2 + Y^2 + Z^2}$$

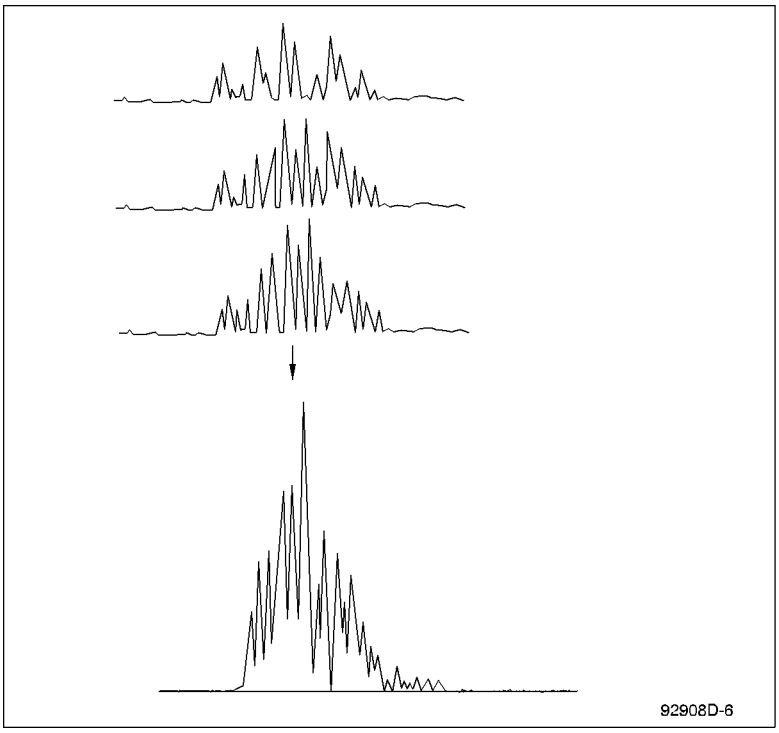

Figure D-3. The Vector Magnitude Waveform.

The M1754A report provides measurements for all of the late potentials criteria on the individual X, Y, and Z leads as well as on the vector lead.

Measurements

In order to quantify late potentials, several measurements are derived from the individual leads as well as the vector composite. Before accurate measurements can be made the QRS onset and offset must be accurately determined. The M1754A automatically determines the QRS onset and offset but manual adjustments can be made to refine their positions.

QRS Duration

The first measurement is the filtered QRS duration—QRSD. Figure D-4 shows the filtered vector magnitude in a patient with late potential activity. The filtered QRS duration is 151 ms.

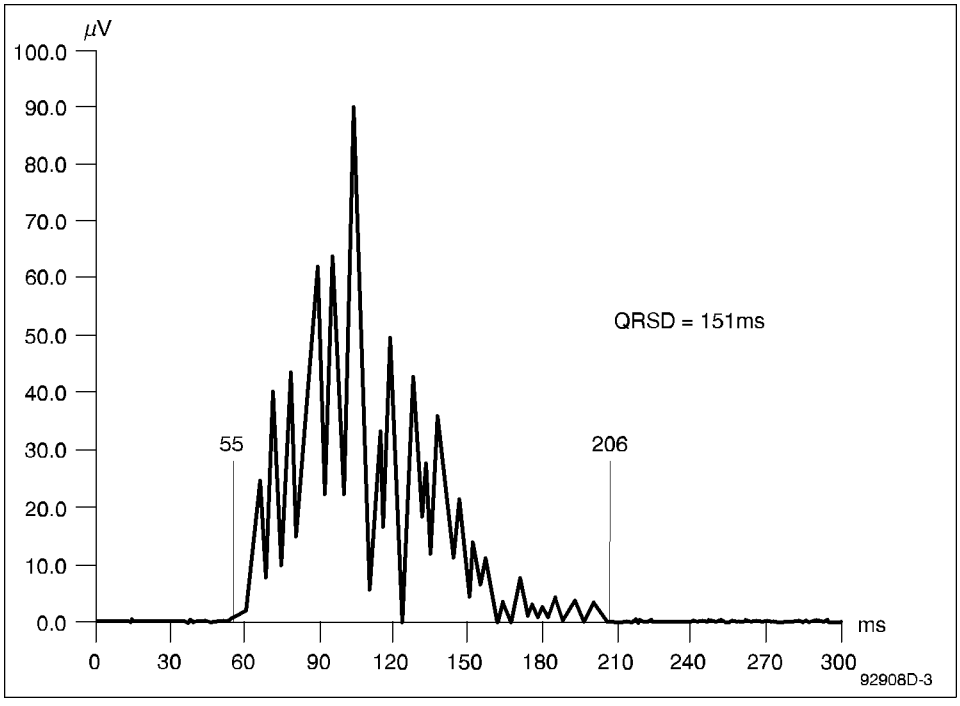

Figure D-4. QRS Duration.

The filtered QRS duration is a simple yet powerful value for quantifying the presence of late potentials. Late potentials cause the QRS duration to be longer than normal. However, in patients with much conduction system delay (right or left bundle branch block) the underlying conduction system abnormality can mask the presence of late potential activity. In these patients the filtered QRS duration alone can not differentiate between patients with and without late potentials. However, these patients can often be assessed using the other late potentials measurements derived from the vector magnitude waveform.

Terminal RMS Voltage

The second value used to identify late potential activity is the amount of energy in the last 40 ms of the vector magnitude waveform. This value is named the terminal RMS (Root Mean Square) voltage—RMS 40.

Figure D-5 shows the terminal RMS voltage as the shaded area at the end of the vector magnitude waveform. The terminal RMS voltage in this subject with marked late potential activity is 3.24 μV. Since late potentials are low amplitude signals which increase the length of the QRS, the RMS voltage measurement from the last 40 ms will be much smaller than normal if there are late potentials present.

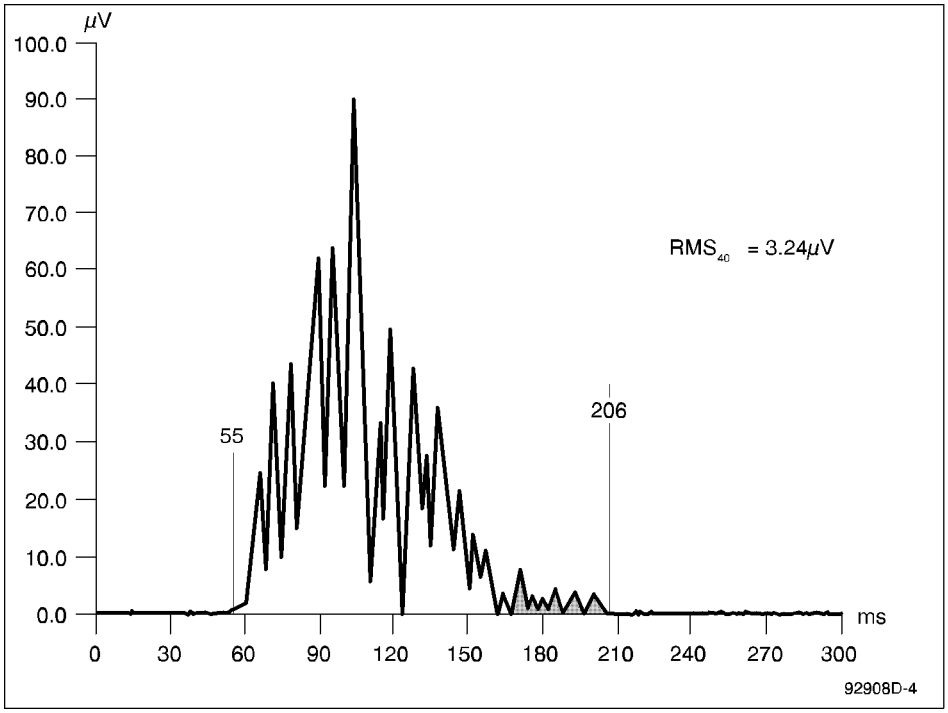

Figure D-5. Terminal RMS Voltage.

Low Amplitude Signal Duration

The third value used to identify late potential activity is calculated as the duration of the end of the QRS waveform which lies below the 40 μV threshold. This value is the Low Amplitude Signal duration—LAS.

Figure D-6 shows the low amplitude signal duration in a patient with late potential activity. The algorithm determines the QRS offset, then moves backwards until it identifies the point when the QRS complex reaches the 40 μV level. That point is marked and a calculation is made of how much of the end of the QRS complex in milliseconds lies under the 40 μV level. In this patient with late potentials activity the LAS duration is 76 ms, which is longer than normal.

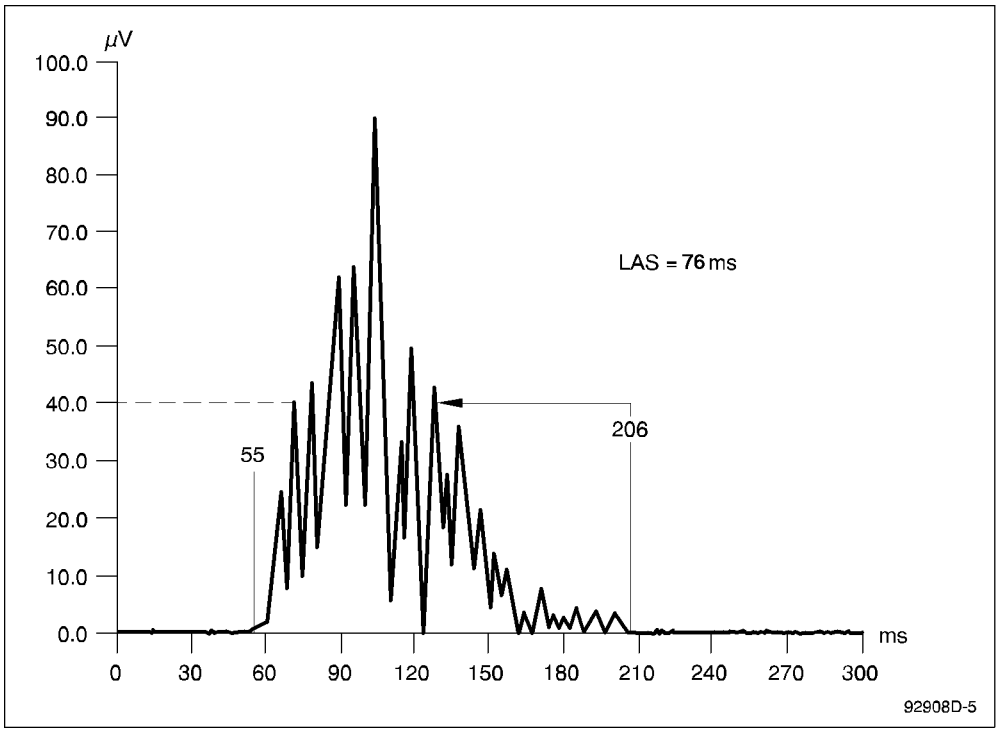

Figure D-6. Low Amplitude Signal Duration.

Total RMS Voltage

Another value used in some studies to characterize the signal-averaged QRS is the Total RMS voltage—RMS. It is a measure of the total energy in the QRS from onset to offset, and is shown as the shaded region in Figure D-7.

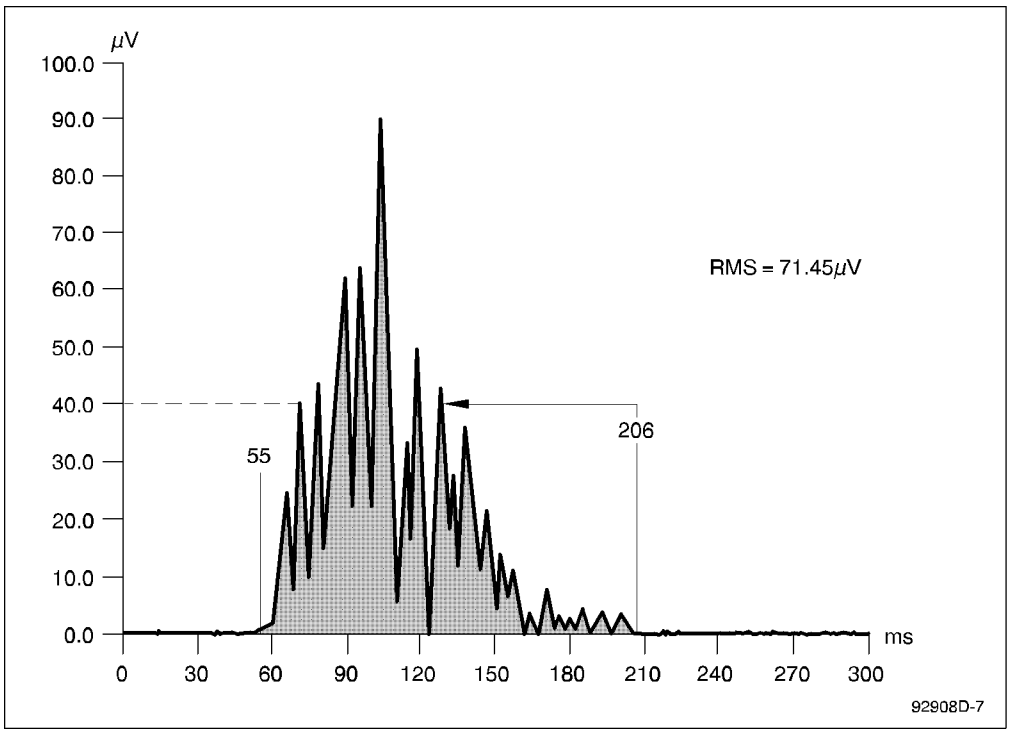

Figure D-7. The RMS Voltage.

Understanding the M1754A ECG Signal-Averaging Report

The SAECG report summarizes the SAECG test results numerically and graphically. Figure D-8 shows the five basic sections of the report that are described in this section.

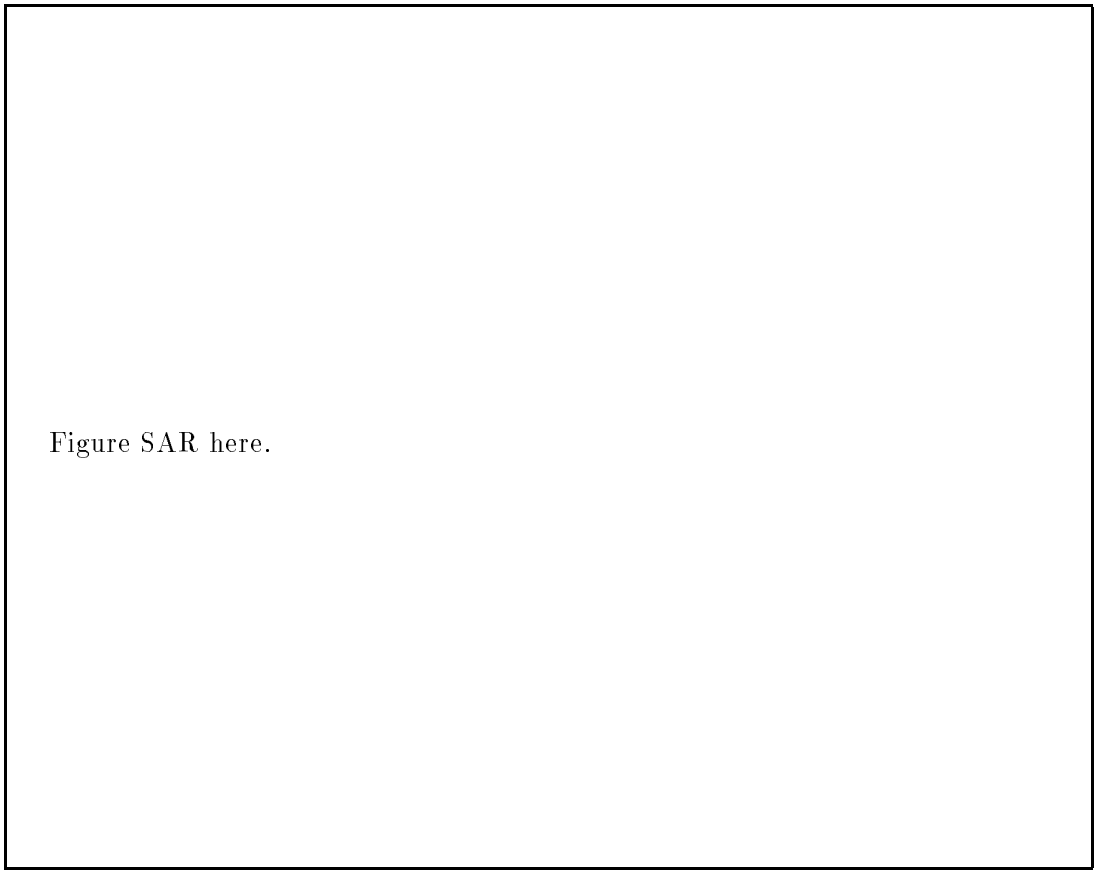

Figure D-8. The SAECG Report.

A. Patient Information

B. Report Settings

C. Individual Lead and Vector Measurements

D. Unfiltered Leads

E. Absolute Filtered Leads

F. Vector Magnitude

Patient Information

The patient information on the report (Figure D-8, reference A) includes patient identification, date and time, department identification, room number, and operator identification. Relevant comments added at the time of the test are also included in the patient information area.

Report Settings

The settings listed on the report (Figure D-8, reference B) reflect settings specific to the report. The following table describes the five report setting listings.

Table D-1. Report Settings

Setting	Description
File	The name of the file. (Up to 8 characters with an optional 3 character suffix.)
Number of beats	How many beats were averaged for this report.
Final noise	The noise level when averaging was completed.
High pass frequency	The high pass frequency filter.
Sampling frequency	How many samples per second were acquired.

Individual Lead and Vector Measurements

The final absolute filtered lead and vector measurements are listed numerically in the upper right corner of the report (Figure D-8, reference C). The following table describes the measurements that are listed.

Table D-2.
Individual Lead and Vector Measurements

Parameter	Value	Description
QRSD	millisecond	QRS duration, measured from its onset to its offset
RMS	microvolt	Root mean square voltage of the QRS complex (onset to offset)
RMS40	microvolt	Root mean square voltage of the final 40 milliseconds of the QRS complex
LAS	millisecond	Low amplitude signal duration (below 40 μV)

Unfiltered Leads

A graphic representation of the final averaged beats of the individual X, Y, and Z leads is shown in the unfiltered leads portion of the SAECG report (Figure D-8, reference D). The beats are shown before filtering.

Absolute Filtered Leads

A graphic representation of the final averaged beats of the individual X, Y, and Z leads is shown in the filtered leads portion of the SAECG report (Figure D-8, reference E). The beats are shown in absolute value after filtering and are magnified.

Vector Magnitude

A graphic representation of the amplitude of the lead vector is shown in the vector magnitude section of the report (Figure D-8, reference F). The vector magnitude is derived from the following equation.

$$\sqrt{X^2 + Y^2 + Z^2}$$

Bibliography

If you are interested in knowing more about the use of signal-averaged ECGs in the determination of late potentials, the following articles provide more information.

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Glossary

AC filter:
The configurable filter which screens out ECG artifact caused by electrical interference.

adult criteria:
Interpretive rules used when analyzing ECGs of persons aged 16 years or older. (See *ECG analysis*, *analysis criteria*, and *pediatric criteria*).

AHA leads:
ECG lead names and identifying colors recommended by the American Heart Association. Limb leads are labeled RA, LA, LL, RL. Chest leads are labeled V1-V6. (See *IEC leads*).

alphanumeric:
Composed of both letters and numbers. HP interpretive cardiographs have an alphanumeric keyboard.

alternating current (AC):
Electrical current provided by wall outlets. AC may be either 60 or 50 Hz depending on country.

analysis criteria:
Rules used to interpret ECGs. (See *adult criteria*, *pediatric criteria*, and *ECG analysis*).

artifact:
ECG waveform distortion that may diminish ECG quality. ECG artifact (or noise) may be caused by electrical interference, poor electrode connections, or patient movement.

artifact filter:
Hewlett-Packard term for filter which screens out noise on the ECG caused by muscle tremor. Operators turn on the artifact filter by pressing the Filter key on the key panel.

Auto ECG:
Twelve-lead ECG recorded and analyzed over a ten second period and printed in a preselected format.

AutoCopy:
Hewlett-Packard term for user-configurable option which programs the cardiograph to automatically copy any Auto ECG recorded.

AutoDial:
Hewlett-Packard term for user-configurable option which programs the cardiograph to transmit an ECG to a particular site when the operator presses `Transmit`.

AutoStore:
Hewlett-Packard term for user-configurable option which programs the cardiograph to automatically store any Auto ECG recorded.

baseline wander:
A slow upward or downward motion on the baseline of any ECG waveform.

baseline wander filter:
The configurable filter which reduces baseline wander.

battery
Hewlett-Packard term for process cardiograph uses to turn off automatically after a preset time period to conserve power. The number of minutes before battery timeout can be set in configuration mode.

baud rate:
The speed at which data (ECGs) can be transmitted from one instrument to another.

Cabrera:
An alternative limb lead order in which aVR is inverted and shown as −aVR. Lead order is aVL, I, −aVR, II, aVF, III. The chest leads are shown in the standard order, V1 - V6. (See *standard leads*. Also see **Questions and Answers** in this *Physician's Guide*.).

calibration pulse:
A 200 ms, 1 mV square wave pulse which appears on the printed record. Calibration pulse shows the sensitivity at which the ECG was recorded and may show the effect of the filters.

CheckDisk:
Hewlett-Packard term for softkey function which checks the percentage of flexible disk storage available for storing Auto ECGs.

configuration:
The manner in which the cardiograph is programmed to function. When the software is installed, the cardiograph defaults to a preset configuration which may be changed at any time.

cycle power:
To press the On-Standby button to **Standby** and then back to **On**.

Data Comm port:
The cardiograph connector into which the modem data cable or direct connection cable is inserted for ECG transmission.

ECG analysis:
Computerized process for measuring and interpreting an Auto ECG.

ECG report:
Paper copy produced by HP cardiographs when the operator presses one of the Auto start keys. This report includes a graphic representation of the heart's electrical activity (ECG waveforms) and identifying information and may also include interpretive information produced by the computerized analysis software. ECG reports must be overread by qualified physicians.

ECG-Log:
Hewlett-Packard term for the softkey function which accesses the list of the last 60 ECGs recorded on a cardiograph.

file:
Data such as an Auto ECG stored on a flexible disk.

flexible disk:
A disk which can be inserted in the disk drive to store data such as Auto ECGs or the system configuration. Flexible disks can also be used to load software.

format:
The manner in which ECG waveforms are presented on the printed ECG report. ECG format is selected by the operator.

Frank leads:
Lead system which obtains three dimensional ECG waveform information. This information is presented using the three orthogonal leads X, Y, and Z.

frequency response:
The range of frequencies in which the cardiograph records ECG data.

front panel:
Cardiograph area that includes the front panel display and the keyboard.

global configuration:
Hewlett-Packard term for general cardiograph function settings. (See *configuration*).

Hertz (Hz):
A unit of electrical frequency (cycles per second).

ID fields:
Hewlett-Packard term for the areas where variable patient information can be entered. Using the ID fields, the operator can key in information such as patient identification number, name, and age.

IEC leads:
Lead names and identifying colors recommended by the International Electrotechnical Commission standard. IEC limb leads are labeled R, L, F, and N. Chest leads are labeled C1–C6. (See *AHA leads*).

jittery waveform:
Irregular up and down movement on the baseline of the ECG often caused by patient movement or muscle tremor.

Manual ECG:
ECG report format which runs continuously until the operator stops the recording. The ECG may show three, six, or twelve lead waveforms. Many institutions and physicians may identify this format as a rhythm strip.

measurements:
The amplitudes, durations, areas, and intervals which characterize the ECG waveform.

menu key:
Cardiograph key that changes the menu selections displayed on the cardiograph's front panel display.

modem:
Device used to transmit data (ECGs) over phone lines.

morphology:
Related to the shape of the ECG waveform.

operator:
The person who records the ECG.

overread:
To review an ECG report. This review must be completed by a qualified physician.

password:
Private code word that limits access to the cardiograph's configuration software to those persons knowing the code word. Passwords prevent accidental or unauthorized changes to cardiograph configuration.

patient module:
Hewlett-Packard term for remote unit that contains all of the cardiograph's ECG data acquisition electronics, the display where electrode status appears, and a remote start/stop key. The patient module connects to the patient data cable and to the leads attached to the patient.

pediatric criteria:
The interpretive rules used when analyzing ECGs of persons aged 15 years or younger. (See *adult criteria, ECG analysis,* and *analysis criteria*).

preliminary report:
An ECG report that has not been reviewed by a qualified physician. (See *overread*).

preview screen:
Hewlett-Packard term for screen which, when installed on the cardiograph, shows the ECG traces as they will appear on the printed ECG report.

research lead set:
Optional leads that can be positioned wherever needed in addition to standard, 12 lead set. Research leads are unipolar.

rhythm strip:
Hewlett-Packard term for ten second recording of a particular lead that is printed at the bottom of an Auto ECG report. (See *Manual* and *Auto ECG*).

shorting plug:
Small spacer plug inserted in patient module lead slot when lead is not in use.

softkeys:
Function keys labeled in the lower portion of the cardiograph's front panel display and physically positioned underneath the display. These keys change functions when they are pressed. The matching display label also changes.

standard leads:
The conventional twelve lead order is I, II, III, aVR, aVL, aVF, V1 - V6. (See *Cabrera*).

Store-Log:
Hewlett-Packard term for function which accesses list of all ECGs stored on the flexible disk.

transmission site:
Hewlett-Packard term for four preset, configurable transmission selections. Operators may select connection type, baud rate (if appropriate), phone number (if appropriate), dialing type (if appropriate), and pausing length (if appropriate).

Welsh cups:
Reusable electrodes held in place with suction cups.