Manual 5

Electrocardiography

The National Heart, Lung, and Blood Institute
of the National Institutes of Health

Atherosclerosis Risk in Communities Study Protocol

Manual 5

Electrocardiography

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FOREWORD

This manual, entitled Electrocardiography, is one of a series of protocols and manuals of operation for the Atherosclerosis Risk in Communities (ARIC) Study. The complexity of the ARIC Study requires that a sizeable number of procedures be described, thus this rather extensive list of materials has been organized into the set of manuals listed below. Manual 1 provides the background, organization, and general objectives of the ARIC Study. Manuals 2 and 3 describe the operation of the Cohort and Surveillance Components of the study. Detailed Manuals of Operation for specific procedures, including those of reading centers and central laboratories, make up Manuals 4 through 11. Manual 12 on Quality Assurance contains a general description of the study's approach to quality assurance as well as the details for quality assurance for the different study procedures.

The version status of each manual is printed on the title sheet. The first edition of each manual is Version 1.0. Subsequent modifications of Version 1 (pages updated, pages added, or pages deleted) are indicated as Versions 1.1, 1.2, and so on, and are described in detail in the Revision Log located immediately after the title page. When revisions are substantial enough to require a new printing of the manual, the version number will be updated (e.g., Version 2.0) on the title page.

ARIC Study Protocols and Manuals of Operation

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1	General Description and Study Management
2	Cohort Component Procedures
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4	Pulmonary Function Assessment
5	Electrocardiography
6	Ultrasound Assessment a. Ultrasound Scanning b. Ultrasound B-mode Image Reading Protocol
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8	Lipid and Lipoprotein Determinations
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Manual 5. Electrocardiography

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PREFACE

Electrocardiograms (ECGs) are coded for ARIC cohort participants and for hospital surveillance cases.

Three different categories of resting ECGs are being collected in the cohort component of the ARIC study.

1. Standard and 2-minute rhythm strip ECGs for every participant at baseline visit

   To determine ECG status of each participant at baseline and provide predictive data for future subgroup analysis.

2. Standard and 2-minute rhythm strip ECGs for every participant at each follow-up visit

   To determine changing ECG status in regard to myocardial ischemia, left ventricular hypertrophy, conduction delays, and arrhythmias for each participant.

3. Hospital ECGs for participants hospitalized after their baseline visit

   To determine if a myocardial infarction has occurred.

ECGs, from baseline and follow-up visits, for all participants are sent by phone modem to be analyzed by computer at the ARIC ECG Computing Center in Halifax. Wave voltage and duration measurements are taken (including U-wave measurement and the Dalhousie multivariable score for left ventricular mass, Appendix J) as well as implementation of the Minnesota Code (1) (Appendix K1) and the Cardiac Injury Score (2) (Appendix L). All records with Minnesota Code findings by the computer, as well as a random sample with no findings, are adjudicated at the ARIC Minneapolis ECG Reading Center in Minneapolis. Paper records are generated by the Halifax ECG Computing Center (Appendix A) and coded on forms (Appendix B) in the Minneapolis ECG Reading Center. All remaining ECGs are also generated by Halifax and kept on file at the Minneapolis ECG Reading Center.

1. BASELINE ECGs

1.1 Introduction

During the baseline examination, a standard supine 12-lead resting ECG and 2-minute rhythm strip are recorded after a 12-hour fast followed by a light snack and at least one hour after smoking or ingestion of caffeine.

1.2 Procedures for Recording Baseline and 2-minute Rhythm Strip ECGs

The standard electrocardiograph for the ARIC study is the MAC PC Personal Cardiography by Marquette Electronics, Inc. The standard configuration for the MAC PC is shown in Appendix A. A 12-lead resting ECG tracing is obtained consisting of 10 seconds of each of the leads simultaneously (I, II, III, aVR, aVL, aVF, V1-V6). The rhythm strip is a full two minutes of Leads VI, II and V5.

Procedures for charging the battery of the MAC PC: The MAC PC runs only from its battery. The battery can be charged by plugging the unit into a wall outlet. The MAC PC will record and print about 50 ECGs on one charge. The amount of charge left is displayed for one-half second when the machine is turned on. It takes about 10 hours to charge the battery.

Plug in the unit each evening after transmitting data to Halifax. Unplug the unit in the morning. It is not good for the machine to spend several days in either the fully charged or completely drained state. For weekends and holidays the machine may be left plugged in, or, if the brief charge display shows at least 25 ECGs remaining, it may be left unplugged.

1.3 Electrode Position Measuring and Marking

Because it is essential for the study to be able to compare baseline ECG data with subsequent records, a uniform procedure for electrode placement and skin preparation is required. The method and procedure for standardizing electrode locations are outlined below.

The participant, stripped to the waist, is instructed to lie on the recording bed with arms relaxed at the sides. The individual is asked to avoid movements which may cause errors in marking the electrode locations, but encouraged to converse with the technician. Prior experience with electrocardiograms is discussed, as is the purpose of the ECG recording. The participant should be told this is a research ECG to be used for statistical analysis later in the study. However, it can also be used by the clinic physician for general diagnostic purposes, and a copy can be sent to the individual's private physician.

For best electrode/skin interface, place the electrodes on the skin at least 2-3 minutes before taking the ECG. Patient information can be entered on the MAC PC during this time.

A good felt tip pen is used to mark the six chest electrode positions. Wipe the general area of the following 10 electrode sites with a sterile alcohol prep to remove skin oil and perspiration. It is extremely important that care be taken to locate these positions accurately. Therefore, the procedure given below must be meticulously followed. Electrode positions in women with large, pendulous breasts must be determined in relation to the anatomic points described below - as for all participants. The electrodes must then be placed on top of the breast (in the correct position).

1.3.1 Limb Leads

Locate electrode LL on the left ankle (inside).
Locate electrode RL on the right ankle (inside).
Locate electrode LA on the left wrist (inside).
Locate electrode RA on the right wrist (inside).

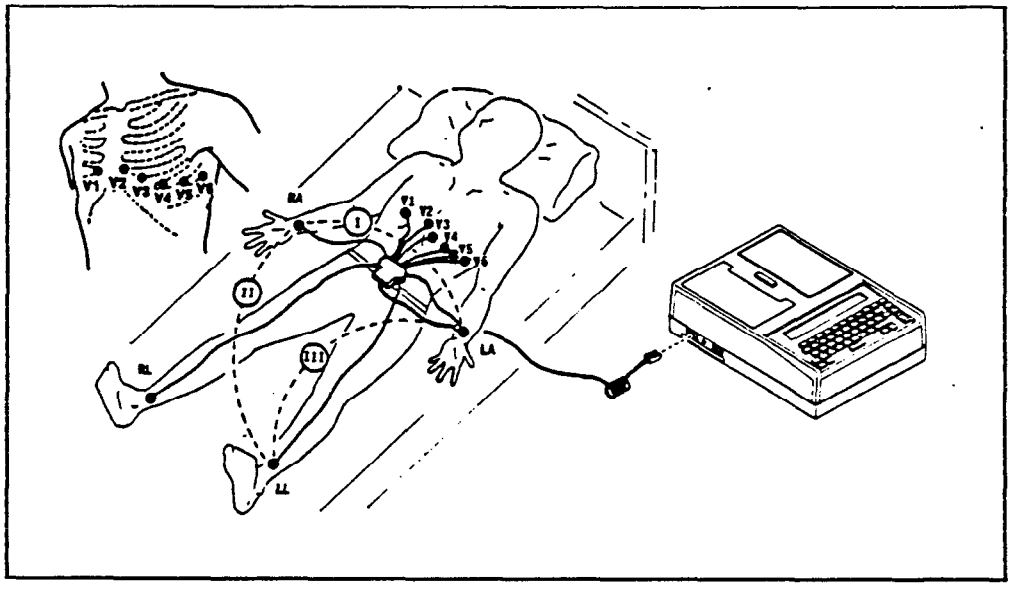


Figure 1. Electrode and Leadwire Placement

1.3.2 Electrode V2

Locate the sternal angle and second left rib between the index and middle fingers of your right hand. Count down to the fourth rib and identify the fourth intercostal space below it. Locate V2 in the fourth intercostal space immediately to the left of the sternal border.

1.3.3 Electrode V1

Locate electrode V1 in the fourth intercostal space at the right sternal border. This should be at the same level as V2 and immediately to the right of the sternum.

1.3.4 Anterior 5th Interspace Marker (E Point)

Identify the fifth rib and fifth intercostal space below V2 by counting down ribs as described for V2. Follow this space horizontally to the midsternal line and mark this point. This is the "E" point.

1.3.5 Electrode 6

With the chest square held lightly against the body (see Figure 2) locate the V6 electrode at the same level as the E point in the midaxillary line (straight down from the center of the armpit). If breast tissue is over the V6 area, mark the V6 location on the breast.

Do not attempt to move the breast in order to mark V6 on the chest wall.

1.3.6 Electrode V4

Electrode V4 is located using the E-V6 Halfpoint Method (3). Using a medical tape measure (American Hospital Supply, Cat. No. 30940), measure the distance between the E point and the V6 marking. The tape should be resting lightly on the skin, not pressing into the flesh. The E and V6 marks should clearly be seen above the tape. Without moving the tape, mark the location of electrode V4 midway between E and V6. Record the E-V6 distance (in centimeters) on scratch paper. This value will later be entered into the MAC PC when it asks for "Height".

1.3.7 Electrode V3

Using a flexible ruler, mark the location of electrode V3 midway between the locations of V2 and V4.

1.3.8 Electrode V4

Using a flexible ruler, mark the location of electrode V5 midway between the locations of V4 and V6.

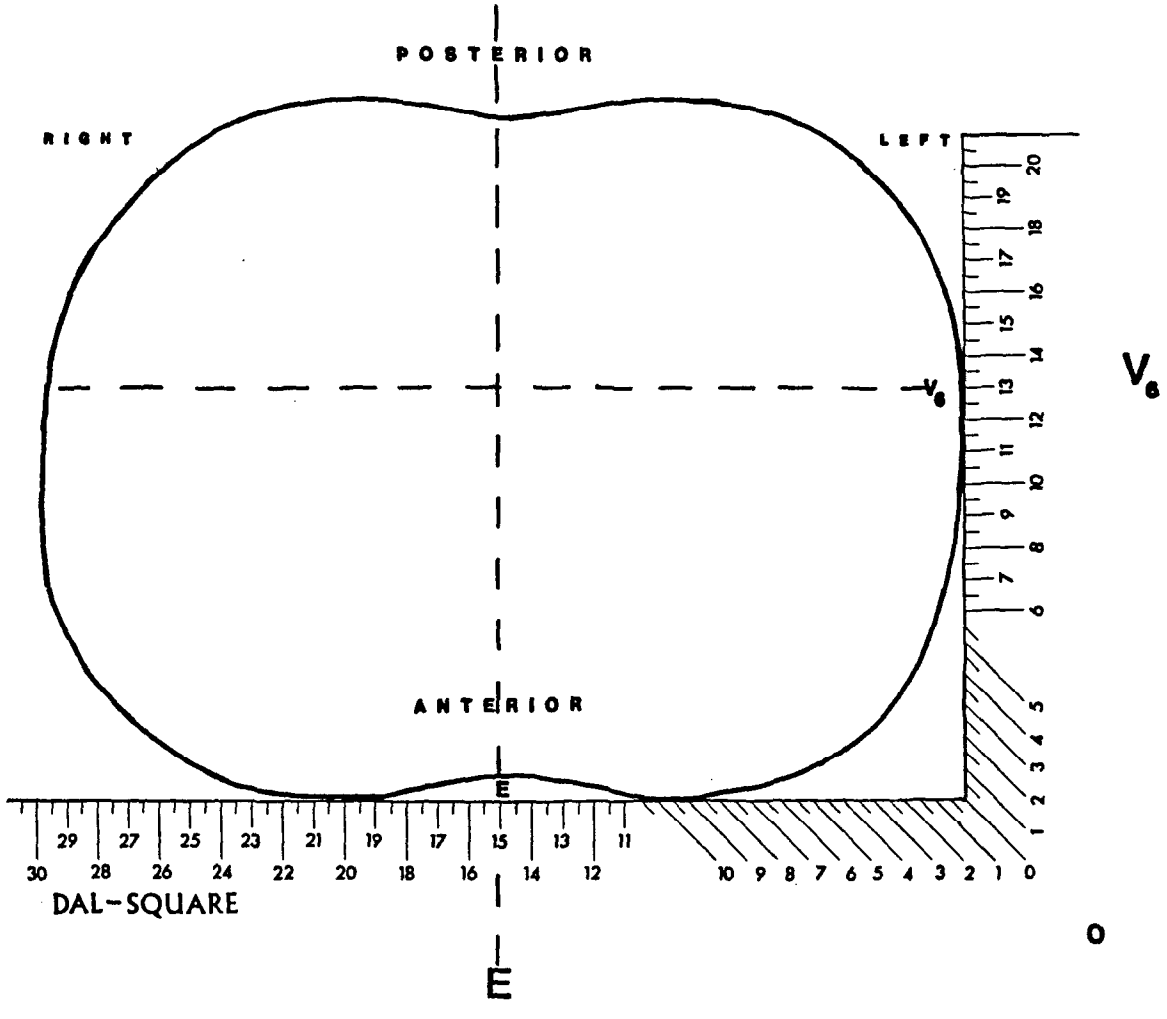


Figure 2. Location of V6 Electrode Using the Dal-Square

1.4 Skin Preparation

Skin preparation is undertaken only in the presence of observed technical problems due to poor electrode contact. As a first step it may be sufficient to rub the skin lightly with a tongue depressor to produce reddening. If this does not resolve the problem, then:

1. With the participant's consent, remove any excess hair from each electrode site on the chest using an electric shaver.

2. At each electrode location in turn, the outer horny layer of the epidermis is removed by gentle dermal abrasion with a piece of 6-0 (220) sandpaper. Only three passes (in the form of an asterisk) at each site using light pressure are required.

If the skin preparation has removed the felt pen marking at any of the electrode sites, these are accurately re-established by carefully repeating the procedure described in Electrode Position Measuring and Marking. It is important that the electrode sites be marked using the exact technique described.

1.5 Application of Electrodes

Disposable electrodes are used in the ARIC study. Adaptors are used with the leadwires to connect the "banana" plug from the MAC PC leadwire to the disposable electrode via a clip.

When placing each electrode, massage it in a small circular motion to maximize the pre-gel contact with the skin but avoid overlap of gel from one electrode to the next.

Center the four limb electrodes on the inside of the wrist or ankle with the tab for the clip pointing toward the head. Center the six chest electrodes on the chest markings with the tabs pointing down. Do not let the electrodes overlap or touch each other if possible.

Clip the appropriate leadwire to each electrode (Figure 1). Do not pull or jerk tangled wires. To untangle wires, disconnect lead wires from electrodes.

1.6 Recording the 12-lead ECG

Change the roll of paper as needed. Each roll is 75 feet long; each patient takes approximately eleven feet of paper (12-lead and 2-minute rhythm strip).

Each ECG is automatically stored in memory until it is deleted.

After placing the electrodes on the skin, enter the participant information into the MAC PC (Figure 3) according to Appendix B. Electrodes must be on the skin for at least 2-3 minutes before taking the ECG. Make a final check of the electrodes and lead wires. Ask the participant to relax and keep still, then press the RECORD key.

The machine will display "Acquiring Data" and the left side of the display will show a count. If there are technical problems the display will show which lead is involved and will keep counting until it gets 10 seconds of good data. Check electrode contacts and leadwires, then check the display again. If the display counts past 75, push the STOP key and remove the throw-away electrodes. Prepare the electrode sites as discussed in Skin Preparation and follow the above protocol for exact relocation of electrodes. Press RECORD ECG. The machine will tell you to "enter a new patient or press RECORD." Press RECORD ECG a second time to start the ECG. The machine will automatically print the ECG after it has acquired 10 seconds of good data (Appendix C).

Tear the ECG off the machine and file it in your records.

1.7 Taking the Two Minute Rhythm Strip

The rhythm strip is taken immediately after the 12-lead ECG is printed and filed. The machine automatically labels the strip with the current participant's acrostic, ID and date. The visit number and technician number must be written on the strip. The rhythm strip is taken at a paper speed of 25 mm/sec (as is the 12-lead ECG).

a) Have a stop watch or a watch with an accurate second hand ready to time exactly two minutes of rhythm strip.
b) Press the 3-lead ECG key. (For wandering baseline it might help to press this three times quickly.) The rhythm strip will immediately begin to print. (See page 4-1 of the Operator's Guide).
c) Start timing the 2 minutes when the baseline is stable.
d) To stop printout after two minutes, press the Main Menu symbol.
e) Immediately begin folding the 10 feet of rhythm strip accordion style, six inches to a side. The Minneapolis ECG Center will return any rhythm strip that is rolled or folded around itself. Do not cut the strip. See Appendix D.
f) Write the visit number and technician number on the strip (Appendix D).
g) Collect rhythm strips in a folder.
h) Every Friday send the strips with a packing list to the Minneapolis ECG Center via certified mail with return receipt. Send them to:

Lowell Hedquist
ARIC ECG Reading Center
611 Beacon St., S.E.
Stadium Gate 27
Minneapolis, MN 55455

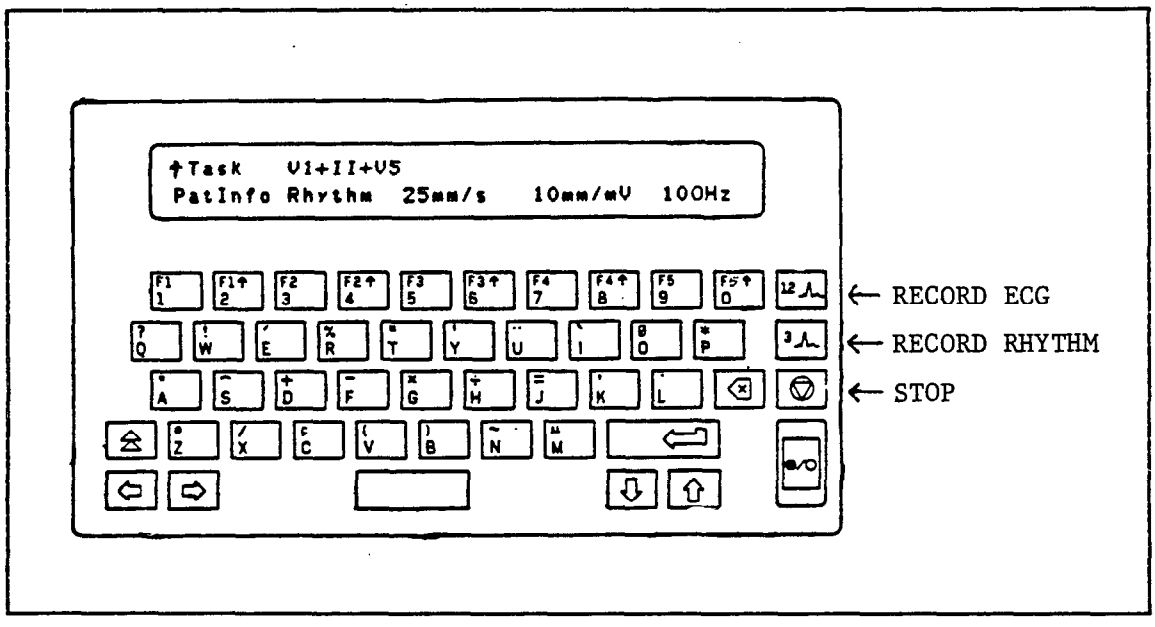


Figure 3. The MAC PC Keyboard and LCD Display by Marquette Electronics, Inc.

1.8 Fault Detection Procedures

Should problems with noise or drift be encountered, electrodes are replaced. The following is a guide for determining which electrodes may be faulty. The underlined electrodes are the predominant determinants of the appropriate lead and therefore are most likely to be the faulty electrodes for a given lead. After adjustment or replacement of suspect electrodes, the electrocardiograph should be able to record 10 seconds of good data.

Lead Affected	Possible Faulty Electrode
I	RL, <u>RA</u>, <u>LA</u>
II	RL, <u>RA</u>, <u>LL</u>
III	RL, <u>LA</u>, <u>LL</u>
aVR	RL, <u>RA</u>, LL, LA
aVL	RL, LL, RA, <u>LA</u>
aVF	RL, <u>LL</u>, RA, LA
V1	RL, LL, RA, LA, <u>V1</u>
V2	RL, LL, RA, LA, <u>V2</u>
V3	RL, LL, RA, LA, <u>V3</u>
V4	RL, LL, RA, LA, <u>V4</u>
V5	RL, LL, RA, LA, <u>V5</u>
V6	RL, LL, RA, LA, <u>V6</u>

1.9 Self-Evaluation of Technical Performance

This section allows technicians to monitor their own ECG technique. It is intended to help technicians who are having difficulty meeting the quality standards set by the ECG Reading Center. These data are not intended to be collected by the study.

The technician examines the ECG tracing to estimate the noise level and baseline drift. Based on the requirements of the Minnesota Code, acceptable and unacceptable levels of noise and baseline drift have been established. These levels are scored using the following table:

Quality Grade	Noise (mm)	Overall Drift (mm)	Beat-to-beat Drift (mm)
1	< .25	< 1	< 1
2	< .50	< 2	< 1.5
3	< 1	< 3	< 2
4	< 2	< 4	< 3
5	≥ 2	≥ 4	≥ 3

The grade levels given in this table are related to the ability of the analysis program to achieve the required accuracy. <u>Quality Grade 5 is unacceptable</u>. ECGs of Quality Grade 5 must be deleted from the machine's memory and retaken immediately.

1. First, the tracing is examined for obvious errors such as right arm/left arm and other common lead misplacements (see Figure 4, negative p-waves in I indicate lead switch). These ECGs must be deleted from the machine's memory and retaken immediately.

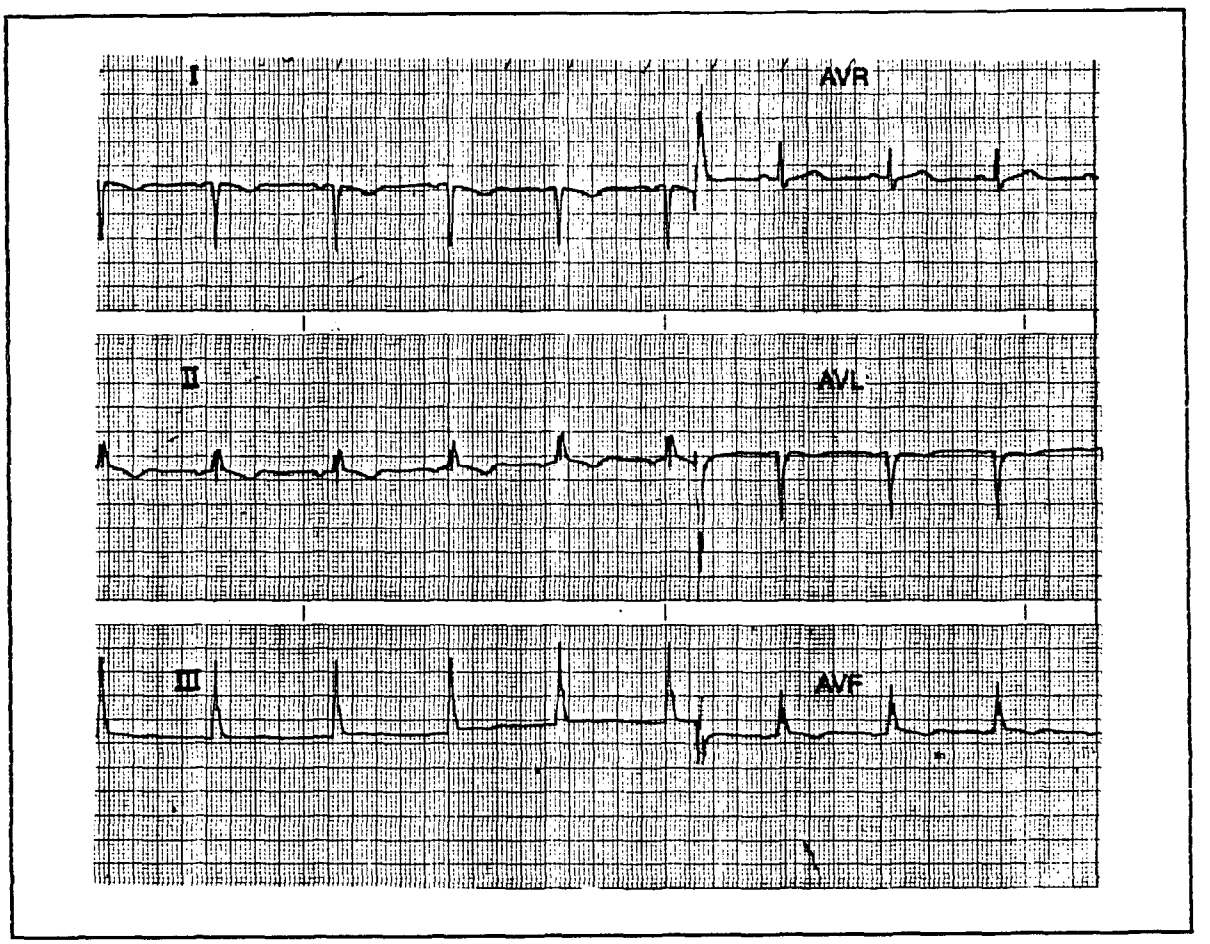


Figure 4. Right Arm/Left Arm Lead Switch

2. The Quality Grade for noise is obtained by measuring the noise level as vertical peak-to-peak values in terms of number of small paper divisions (smallest grid squares). Note that recording sensitivity is 1 mv per centimeter, (one small paper division = 1 mm = 0.1 mv). A noise level of more than 2 small paper divisions (> 0.2 mv peak to peak) is unacceptable (Figure 5).

3. The Quality Grade for overall drift is obtained by searching each of the 12-leads for the maximum and minimum baseline levels within that lead (as determined by the PR and/or TP segments) over the 10 second recording and measuring the vertical distance between them. A distance of more than 4 small paper divisions is unacceptable (Figure 6).

4. The Quality Grade for beat-to-beat drift is determined by searching for the pair of successive QRS complexes having the largest amplitude difference (vertical distance) between successive PR segments. A difference of more than 3 small paper divisions (> 0.3 mv) indicates an unacceptable record (Figure 7).

Improvement in technical quality will indeed result if the prescribed procedure for electrode position marking, electrode and skin preparation, electrode replacement and equipment use are carefully followed. Baseline drift problems, which are essentially caused by poor electrode-skin contact are particularly easy to remedy, as is 60-cycle interference.

Sixty-cycle interference is characterized by perfectly regular fine oscillations occurring at the rate of sixty per second (Figure 8).

Electrical equipment of any kind may be the source of AC interference on an ECG in all leads or only certain ones. Check quality of skin preparation and electrode contact. Check leadwires and resecure attachment of the alligator clip to the electrode. Make sure participant does not touch any metal part of the bed or other equipment. Proximity to a wall with hidden wiring or a partially broken cable may also cause this problem.

Muscle Tremor causes irregular oscillations of low amplitude and varying rapidity superimposed upon the ECG waveform (Figure 9). Muscle tremor is the involuntary muscle activity of a participant whose state is tense, apprehensive, or uncomfortable. This is why a clear explanation of the electrocardiogram test and reassurance are necessary for the participant. The participant is asked if the temperature of the room is too low for her/him and is covered with a blanket if so.

1.10 Original Hard Copy Record

The original 12-lead ECG record is filed at the field center. If the clinic needs a second "original" ECG, it can be printed from the machine's memory anytime before deletion of the ECG.

The first hard copy ECGs are read locally by clinic physicians for notification and referral if needed. The records are then placed in participants' local data files. Double-check that this participant is correctly identified.

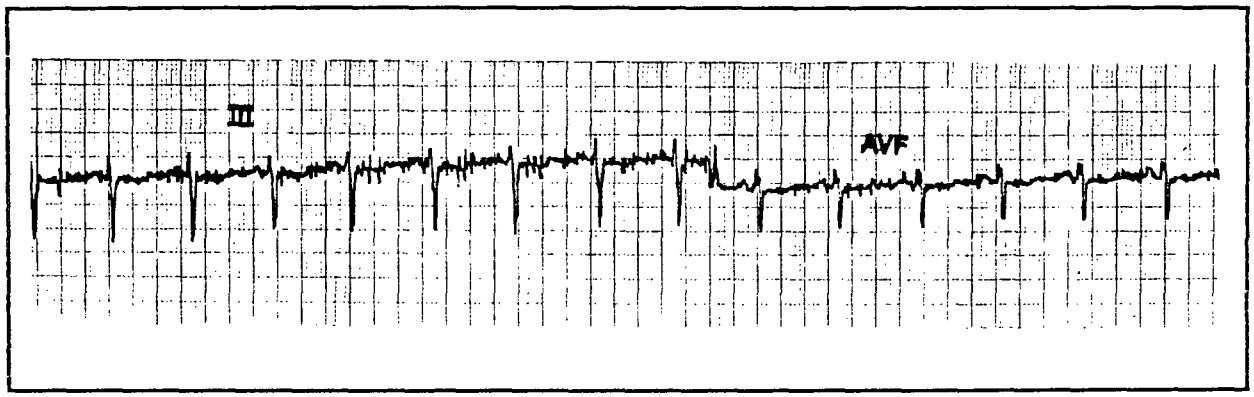


Figure 5. Unacceptable Noise Level

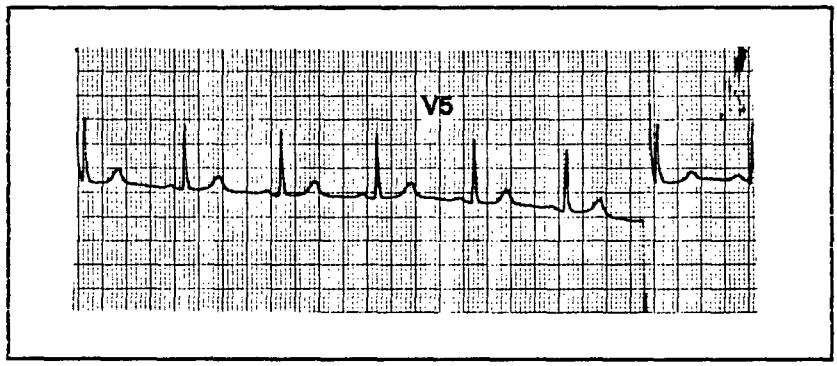


Figure 6. Unacceptable Overall Baseline Drift

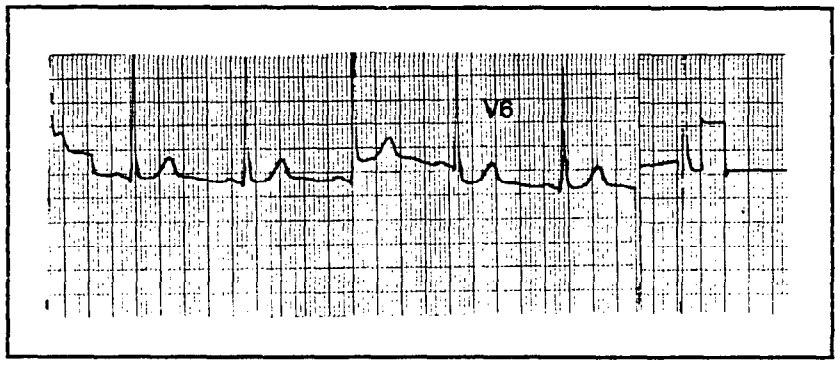


Figure 7. Unacceptable Beat-to-Beat Baseline Drift

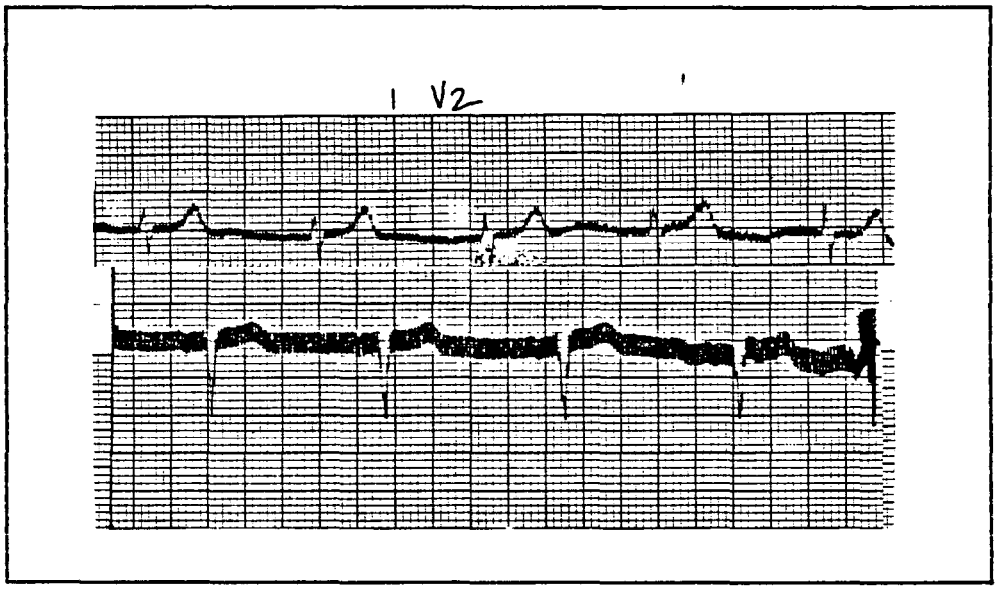


Figure 8. Sixty-Cycle Interference

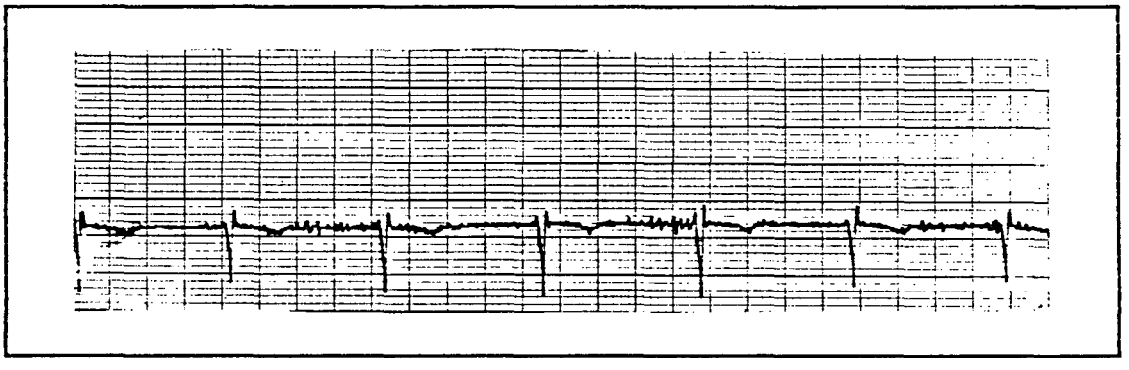


Figure 9. Artifact Caused by Muscle Tremor

1.11 Transmission, Confirmation and Deletion

1.11.1 Transmission

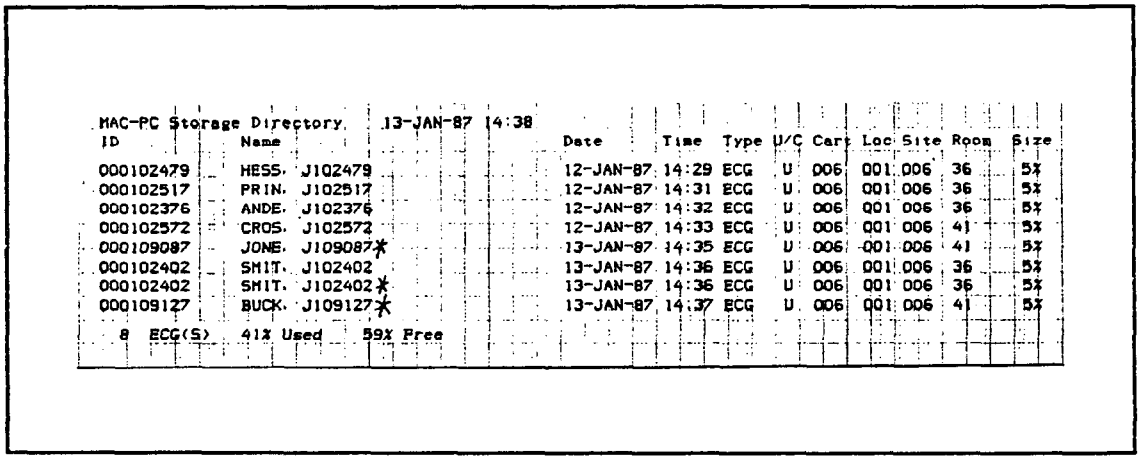
The memory of the electrocardiograph will store 11 to 16 12-lead ECGs. The machine will not store another ECG if the memory is full when an ECG is taken. The machine will ask you to delete an ECG from memory or delete the one just taken. For this reason, ECGs must be transmitted to Halifax every day and deleted the next day after confirmation.

The receiving unit in Halifax is usually in the "ready" state to receive ECGs. If you get a "no connection" message when trying to send ECGs, try again in 10-20 minutes. If there continues to be problems with transmitting to Halifax, ECGs can be transmitted to the MAC 12 at the Minneapolis ECG Coding Center. Call the Coding Center supervisor at (612)624-5872 to arrange transmission.

1. The phone number for the Halifax receiving port (902)424-3644 is already programmed in the set-up menu of the electrocardiograph.
2. Make sure the phone line is connected. This can be done by moving the jack from your regular phone to the port in the back of the MAC PC.
3. Print one copy of the directory of ECGs in memory (see Figure 10). To do this:

    a) From the Main Menu press the shift and F1 simultaneously to show the system functions display.
    b) Press the Storage (F1) key to display the storage functions display.
    c) Press the directory (F2) key and a directory will be printed.
4. On the directory, put an asterisk by the IDs taken that day which are to be transmitted (see Figure 10).
5. To complete transmission:

    a) From the Main Menu press the shift and F1 keys simultaneously to show the system functions display.
    b) Press the Storage (F1) key to display the storage functions display.
    c) Press the More (F5) key to show the second Storage Functions display.
    d) Press the Transmit (F1) key to show the transmission type display.
    e) Press the phone (F1) key. (The Halifax phone number will show on the display and should not need to be re-entered). Press ENTER.
    f) Patient data for the first ECG in memory will be displayed.
    g) If that ID had already been transmitted earlier, press NO (F2). If the ECG is to be transmitted press YES (F1).
    h) Each ID on the directory will be displayed. Press NO or YES for each one, referring to the printed directory. Note in Figure 10 that ID #J102402 has two different ECGs in the machine's memory. This would occur if the technician noticed poor quality in the first ECG, and took a second one without deleting the first. Make sure to transmit only good quality tracings.



MAC-PC Storage Directory 13-JAN-87 14:38

ID	Name	Date	Time	Type	U/C	Cart	Loc	Site	Room	Size
000102479	HESS. J102479	12-JAN-87	14:29	ECG	U	006	001	006	36	5%
000102517	PRIN. J102517	12-JAN-87	14:31	ECG	U	006	001	006	36	5%
000102376	ANDE. J102376	12-JAN-87	14:32	ECG	U	006	001	006	36	5%
000102572	CROS. J102572	12-JAN-87	14:33	ECG	U	006	001	006	41	5%
000109087	JONE. J109087*	13-JAN-87	14:35	ECG	U	006	001	006	41	5%
000102402	SMIT. J102402	13-JAN-87	14:36	ECG	U	006	001	006	36	5%
000102402	SMIT. J102402*	13-JAN-87	14:36	ECG	U	006	001	006	36	5%
000109127	BUCK. J109127*	13-JAN-87	14:37	ECG	U	006	001	006	41	5%

8 ECG(S) 41% Used 59% Free

Figure 10. MAC PC Storage Directory

i) The machine will dial the phone and transmit each ECG.
j) Watch the display as each ECG is transmitted and check the IDs on the Directory List. This way if a problem occurs, the ECG involved can be identified.
k) After the last ECG to be transmitted is displayed, a message indicating the number of ECGs that were transmitted vs. the number you selected to transmit is displayed. If the numbers are not the same, the problem ECGs will have been identified on the Directory List. These can be re-transmitted using the above steps.
l) Keep the Directory List available for confirmation from Halifax via electronic mail the next morning.

1.11.2 Confirmation

Every morning the ECG Computer Center in Halifax notifies each field center of the IDs received. Notification is by ARIC electronic mail directly to the field center's personal computer. The mailing includes the ID, date and time of each ECG received on the previous evening.

Compare the Directory List with the IDs of the mailing. If there is more than one ECG in the directory for a participant, compare the qualities and the times. If the ECGs were of equal quality, compare the times to verify that the earliest record was sent and received.

If there is an ID on the Directory (which had been marked for transmission) that is not on the confirmation mailing, retransmit that ID immediately. If there is an ID on the confirmation mailing that is not on your Directory List, notify Halifax of this through ARIC electronic mail.

Note: Confirmation of transmission from Halifax has nothing to do with the confirmed/unconfirmed report settings in the MAC PC.

1.11.3 Deletion

To delete ECGs that have been received by Halifax:

1. From the Main Menu press the shift and F1 simultaneously to show the system functions display.
2. Press the Storage (F1) key to display the storage functions display.
3. Press the Delete (F4) key.
4. Patient data for the first ECG in memory will be displayed.
5. If confirmation from Halifax has been received, press the Delete (F1) key, otherwise press the save (F2) key.
6. Each ECG in the Directory will be displayed. Press Delete or Save for each one.
7. The machine will count the ECGs and the display will ask if you really want to delete them. If you are sure you have selected only ECGs confirmed by Halifax and/or bad quality ECGs, press Yes (F1), otherwise press No (F2) and start over.
8. You may also press Quit (F4) while any ID is being displayed if you have made a mistake and nothing will be deleted.

2. CENTRAL ECG READING BASELINE ECGS

2.1 Resting 12-lead ECG

Reading of 12-lead ECGs by the ECG Computer Center includes the Minnesota Code (1) (Appendix E) and the Performance Grade Level (Appendix F). Every month Halifax sends these data for the ECGs received in the previous month to the Coordinating Center on diskette (Appendix G). Wave voltage and duration measurements also taken are detailed in Appendix H and include U-wave measurement, the Dalhousie score for left ventricular mass (Appendix I), and the Cardiac Infarction Injury Score (2) (Appendix J). These data are reported at the end of the study.

All resting 12-lead ECG records with computer-generated Minnesota Code findings and at least a 10% random sample with no findings are visually coded at the Minnesota Coding Center by the full Minnesota Code. Results are recorded on the ARIC Cohort 12-Lead Resting ECG form (Appendix K). ECGs are read three times, blinded: the final codes are adjudicated by a senior coder. Minnesota Code criteria are in Appendix E.

Adjudication:

The visual Minnesota Codes are sent to the Coordinating Center for data entry and comparison with the computer-generated codes. Adjudication between the visual code and the computer code is performed by two electrocardiographers only on ECGs that have a discrepancy involving any Q-code, or any ST or T wave changes (4-1, 4-2, 5-1, 5-2 or 9-2). The Coordinating Center determines the IDs that have any of these discrepancies and sends a report form to the Minnesota Coding Center listing the ID, acrostic, date and time of ECG, the visual codes and the computer codes. These ECGs are examined and the adjudicated codes are recorded on the report form which is returned to the Coordinating Center. The Coordinating Center adds the adjudicated codes to the data base as the definitive Minnesota Codes for the IDs involved.

2.2 Two-minute Rhythm Strip

Rhythm strips are coded for arrhythmias on the ARIC Cohort Two Minute Rhythm Strip ECG Coding form (see form Appendix N) at the Minnesota ECG Coding Center. The rhythm strips are stored by field center and ID at the Coding Center.

2.3 Visit Two ECGs

Visit two procedures are the same as for baseline ECGs with the exception that baseline and visit two ECGs are compared. The procedure for this comparison is as follows.

When two ECGs from different field center visits are available, a determination is made at the Coordinating Center as to whether or not Minnesota Code change criteria are met. Determination is made by computer algorithm, not by Minnesota Coders. A list of those IDs that fit the change criteria (i.e., any pattern ED1 through ED7, see Appendix V) is sent to the ECG Coding Center. Only ECGs for these IDs are examined side by side for serial ECG change.

Simultaneous ECG comparison is based on the final Minnesota codes. Serial ECG changes (significant increase, no increase or technical problem) are also determined three times; the final categories are adjudicated by a senior coder and added to the ARIC Minnesota Coding and Serial Change Field Center Visit ECG form (Appendix M). Serial Change criteria are in Appendix L. These objective rules for side-by-side ECG evaluation are used to determine whether a Minnesota code change between ECG pairs is significant. The simultaneous ECG evaluation procedure uses the first clinic visit ECG as the reference ECG for comparison.

ARIC requires a Minnesota Code change plus agreement by simultaneous ECG comparison before declaring that the ECG pattern change meets ARIC ECG criteria for interim MI (see Appendix V).

A determination that an ARIC participant has had an MI, either prior to the initial clinic visit or between visits, can be made on ECG evidence alone, using the following criteria:

1. Prevalent MI at Baseline
   Baseline ECG (initial cohort visit) coded:
   a) any 1-1-X code
      OR
   b) any 1-2-X PLUS 4-1-1 or 4-1-2 or 4-2 or 5-1 or 5-2.

2. Interim MI Between Cohort Visits
   An Evolving Diagnostic ECG Pattern (ED1 through ED7) between the baseline ECG (initial cohort visit) and an ECG from a later cohort visit confirmed by simultaneous ECG comparison.

2.4 Hospital ECGs for Cohort

Whenever hospital ECGs for cohort participants are obtained after the baseline examination, photocopies of these records (masked at the field center for all information except ID) are sent to the Coding Center and coded by the Minnesota Code. ECGs are read three times, blinded: the final codes are adjudicated by a senior coder. Minnesota Code criteria are in Appendix E.

Copies of the coding forms are sent to the Coordinating Center for data entry and a determination is made at the Coordinating Center as to whether or not the Minnesota Code change criteria are met. Determination is made by computer algorithm, not by Minnesota Coders. A list of those IDs that fit the change criteria (i.e., any pattern ED1 through ED7 or EV1 through EV5, defined above) is sent to the ECG Coding Center. Only ECGs for these IDs are examined side by side for Serial ECG change.

Simultaneous ECG comparison is performed on the final Minnesota codes using the first ECG of the hospitalization as the reference. Serial ECG changes are also determined three times, blinded. Serial change categories are: significant increase, decrease (but not for Q-codes), no change (this implies no increase for Q-codes) or technical problem. The final categories are adjudicated by a senior coder and added to the Minnesota Coding and Serial Change Hospital ECG form (Appendix O). Serial Change criteria are in Appendix L. These objective rules for side-by-side ECG evaluation are used to determine whether a Minnesota code change between ECG pairs is significant.

As an example, the ARIC protocol defines a new Minnesota code 1-2-7 as a potential ischemic event. Persons with this severity of ECG change will have simultaneous ECG comparison. The ECG comparison procedure (for this case) requires a $\geq$ 1mm R-wave amplitude decrease between corresponding leads of the reference and comparison ECGs. The criteria for 1-2-7 are QS patterns in V1, V2, and V3. If the reference ECG has R-waves that are $\geq$ 1mm tall in V1 or V2 or V3, then when comparing these ECGs side by side, the R-waves in the reference ECG appear to decrease the appropriate amount (at least 1mm) and a "significant increase" is noted on the Appendix O form. If the reference ECG has R-waves $<$ 1mm tall, it cannot fulfill the change criteria and "no change" is noted (see Appendix W).

ARIC requires a Minnesota Code change plus agreement by simultaneous ECG comparison before declaring that the ECG pattern change meets ARIC criteria for an evolving ECG diagnostic pattern.

The coded forms are returned to the Coordinating Center for data entry and the ECGs are filed by field center and ID at the Coding Center.

2.5 Community Surveillance ECGs

ECGs are read for Q-waves locally in hospital by centrally trained Field Center readers. Coding procedures for Field Center readers to code "Q-wave only" on the ARIC Hospital Surveillance ECG Classification form (Appendix P) outlined below (Section 2.5.1). For quality control, abstractor coding of Q-waves is compared in a sample with full Minnesota Coding at the ECG Reading Center. See Section 3.4.

2.5.1 Procedures for Surveillance Hospital ECGs Coded On-Site at Field Centers

1. Mark one or more of the following in the first line:
   a) Mark "First ECG" if the ECG is the first codable ECG recorded after admission.
   b) Mark "Last ECG" if the ECG is the last codable ECG recorded before discharge.
   c) Mark "Last ECG of day 3" if the ECG is the last codable ECG recorded on day 3 after admission or after an in-hospital event.

   NOTE: Do not chose an ECG if it is uncodable.

2. Indicate in line A1 if an ECG has any of these suppression patterns:
   a) Complete Heart Block (Minnesota Code 6-1)
   The atrial rates (P to P intervals) and the ventricular rates (R to R intervals) are regular but independent.
   b) WPW Pattern (6-4-1 & 6-4-2)
   PR interval < 0.12 sec, QRS duration => 0.12 sec with slurred upstroke to the QRS complex and R peak duration => 0.06 sec.
   c) Implanted Pacemaker (6-8)
   Sharp vertical spikes having a duration too short to measure and occurring at absolutely regular intervals preceding each QRS complex.
   d) Ventricular Fibrillation (8-2-1)
   Irregular undulations of the baseline without clear P-, QRS- and T-wave complexes.
   e) Persistent Ventricular (idioventricular) Rhythm (8-2-2 & 8-2-3)
   QRS => 0.12 sec and absence of preceding P-waves in all beats of ECG.

3. Ignore individual leads with muscle tremor artifact or wandering baseline.

4. Mark line A2 only if all ECGs for a person are uncodable because of:
   a) 3 or more missing leads, (except aVR).
   b) Muscle tremor artifact that produces possible false initial R's.
   c) Other technical errors such as extreme lack of centering or marked clipping which effect the Q-waves.
   d) No calibration mark, or calibration not between 9.75 and 10.25 or 4.75 and 5.25 (half-standard).

5. Indicate in line B if ECG shows either:
   a) Left Bundle Branch Block (7-1-1)
   QRS duration => 0.12 sec in a majority of beats of I, II, III, aVL or aVF PLUS R peak duration => 0.06 sec in a majority of beats of I, II, aVL, V5 or V6.
   b) Right Bundle Branch Block (7-2-1)
   QRS => 0.12 sec in a majority of beats of I, II, III, aVL or aVF
   PLUS
   R' > R in V1.
   OR
   QRS mainly upright and R peak => 0.06 sec in V1 or V2.
   OR
   S duration > R duration in all beats in I or II.

6. Definition of Q-wave
   a) No initial R in any beat in the lead.
   (Except V1 can have initial R's in <=50% of beats).

   Definition of initial R:
   1) amplitude => 0.25mm.
   2) reaches peak within 0.5mm (looks sharp, not rounded).

b) Must have terminal R.

Definition of terminal R:
1) amplitude => 1mm.
2) must fall by 0.25mm within 1mm (looks sharp, not rounded).

c) Must have Q depth => 1mm.

d) Must have Q duration => 1mm.

NOTE: If a Q-wave is less than 1mm deep, any R-wave after it (greater than 0.25mm) is considered an initial R.

7. Definition of QS-wave:
   a) No initial R in any beat in the lead. (Except V1 can have initial R's in <=50% of beats).
   b) No terminal R.
   c) Must be => 1mm deep.

8. A majority of beats in the lead must fit the characteristics required to check C1, C2, D1, D2, E1 or E2.
   a) Example:
   There are Q-waves > 1mm deep in a majority of beats in aVF.
   There are 5 beats in lead III, all with Q-waves:
   If 2 beats have Q=0.03 sec wide (these fit D2) and 3 beats have Q=0.02 sec wide (these fit D3), mark D3.
   If 3 beats have Q=0.03 sec wide and 2 beats have Q=0.02 sec wide, mark D2.
   If there were only 4 beats in III, two that fit D1 and two that fit D2, mark D2.

3. QUALITY CONTROL

3.1 The 12-lead ECG

3.1.1 Technician

1. All ECG technicians must be certified. See the following section on Training and Certification.
2. Study guidelines on "acceptable" noise levels are given earlier in this protocol under Self-Evaluation of Technical Performance.
3. Each technician must take an average of 3 ECGs per week over a two-month period to remain familiar with procedures and equipment.
4. Each technician is observed monthly by the most senior certified technician while taking a participant's ECG. The observer checks whether or not each procedure is performed (Appendix Q) and makes comments on the sheet if necessary. After the ECG is taken, the observer discusses the Procedure Review with the technician, then sends it to the Coordinating Center.

3.1.2 Field Center

1. Each ECG is checked for quality of data in Halifax.
2. The technician number and Performance Grade Level (Appendix F) of each ECG is included in the data file that is sent to the Coordinating Center each month.
3. The Coordinating Center reports these findings to the Field Centers.
4. Each MAC PC is calibrated quarterly. Procedures are in Appendix U.

3.1.3 Halifax ECG Computer Center

1. The ECG Coding Center will establish a test file containing approximately 25 ECGs from each field center, for a total of 100, enriched as to ECG abnormality. This file will be established in collaboration with the Coordinating Center.
2. Every other week, 5 ECGs from this test file will be transmitted to Halifax as a normal clinic transmission. The procedure is as follows: Valid ARIC QC phantom IDs are provided to the Coding Center by the Coordinating Center, along with matched IDs from the test file. The editing function of the MAC 12 is to be used to create a record for each phantom ID by copying the record of the matched test file ID and replacing the original ID with the matched QC phantom ID. The original acrostic will also be replaced with ersatz data. Procedures for this are documented in Appendices R and S.
3. In the event of hardware or software changes at the Halifax ECG Computer Center, the entire test set will be transmitted to Halifax, and the results of processing this retransmission compared to the original results to verify that the computer changes have not altered the computer processing of the ARIC ECG data.

3.1.4 Minneapolis ECG Reading Center

1. Blind rereading of clinic ECGs is performed in two ways:
   a) The abnormal quality control ECGs that are retransmitted to Halifax are returned to the Coding Center with the other abnormals. The Coding Center makes no effort to distinguish these returned ECGs from the rest of a normal shipment from Halifax. They are coded and reported in the usual manner. Thus, the Coding Center continually rereads the quality control ECGs that Halifax determines to be abnormal. (The quality control ECGs that Halifax determines to be normal are only sent to the Coding Center if they are chosen to be part of the 10% sample of normals that is included with the abnormals.)
   b) The Coordinating Center makes comparisons of repeated Reading Center readings by identifying the QC phantom IDs and comparing the results on these with the codes on the original IDs.
2. Halifax will set up a test set of 100 ECGs in consultation with the Coordinating Center.
   a) The Coordinating Center will periodically furnish Halifax with a list of QC phantom IDs, matched to the original IDs in the test set. The IDs on each test ECG to be sent to the Reading Center will be altered to the QC phantom ID matching the original ID on this list.
   b) Halifax will transmit ECGs from this list along with regular transmissions to the Minneapolis Reading Center, at the average rate of 5 per 50 ECGs transmitted. The QC ECGs should be added in the middle of the transmission, not at the beginning or end, so that the QC ECGs cannot be easily picked out.
   c) The Coordinating Center will compare repeated Reading Center readings by identifying the QC phantom IDs and comparing the codes for these IDs to the original codes. The first coding of these ECGs, unless it is changed during adjudication, will be considered the definitive coding.
   d) Comparison of measurements by Halifax and coding by Minnesota will indicate any possible deterioration of quality due to repeated phone line transmission, repeatability of ECG Computer Center measurements, and repeatability of ECG Reading Center Minnesota codes.

3.2 The Two-Minute Rhythm Strip

The Coordinating Center will work with the ECG Reading Center to set up a test library of rhythm strips for resubmission as a quality control check. The Coordinating Center will send periodically a list of IDs from the test set with matched QC IDs. The Coordinator at the ECG Reading Center will submit the corresponding rhythm strips to the coders for coding, and after receiving coding forms, will key in the data under the matched IDs and transmit to the Coordinating Center, where comparisons will be made.

3.3 Cohort Hospital ECGs

The Coordinating Center will gather a library of photocopies of cohort hospital ECGs. These are periodically circulated to the Reading Center for blinded repeated readings. The same originals must always be used when making copies.

The ECG Reading Center will conduct internal repeat quality control on cohort hospital ECGs in the same manner as for two-minute rhythm strips.

3.4 Surveillance Hospital ECGs

The Minneapolis ECG Reading Center coding supervisor will circulate at least once per year to clinics to reread a number of hospital ECGs to be determined by the Coordinating Center and Steering Committee. The coding form is the same as that used by field center readers, Prototype in Appendix P. Cohort hospital surveillance ECGs, from each clinic, are Q-wave coded by abstractors and also photocopied and forwarded to the Minneapolis ECG Reading Center to be coded by the Minnesota code and serial change rules using the form used for Cohort Hospital ECGs, Appendix O. Comparisons are made of Q-wave coding by abstractors and the full Minnesota coding by the reading center on these cohort ECGs.

3.5 Data Acquisition

Quality control of data acquisition will be achieved by initial central training of technicians and subsequent certification of them and all "new" technicians involved during the course of the study. Study guidelines on "acceptable" noise levels are given earlier in this protocol under Self-Evaluation of Technical Performance. Feedback of clinic quality of ECG recording will also be reported by the Halifax ECG Computing Center on receipt of ECGs transmitted by modem. The Performance Grade Level is included for every ECG in the monthly diskette sent to the Coordinating Center.

3.6 Training and Certification

3.6.1 Cohort ECGs

A two-day central training session was held in July 1986 at Johns Hopkins. Training included electrode placement, skin preparation, MAC PC menus and data entry and self-evaluation of technical performance. All new technicians are trained by the most senior certified technician.

The technician responsible for recording ECGs must be officially certified as capable of recording high-quality ECGs by the ECG Center. Certification ECGs must be done on age-eligible participants in the manner described above following return to the clinic after central training. Three ECGs must be obtained. Send the ECGs and the certification form (Appendix T) to the Coordinating Center. The tracing will be "logged in" and forwarded to the ECG Reading Center for review. Notification of the technician's

certification status will be made by the Coordinating Center after this review is complete.

3.6.2 Community Surveillance ECGs

Hospital record abstractors are trained to code Q-waves at the training session for medical record abstracting. Abstractors must demonstrate accuracy of Q-wave coding on a test set of ECGs in order to be certified.

4. REFERENCES

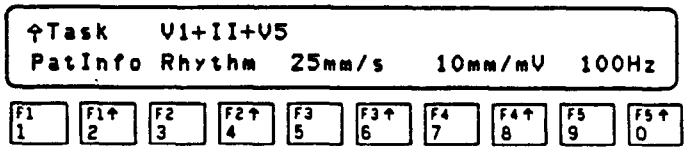
1. The Minnesota Code Manual of Electrocardiographic Findings; Prineas RJ, Crow RS, Blackburn H. John Wright PSG, Inc., Littleton, MA 1982.

2. Rautaharju PM, Warren J, Jain U, Wolf HK, and Nielsen CI. Cardiac Infarction Injury Score: An Electrocardiographic Coding Scheme for Ischemic Heart Disease. Circulation 1981; 64(1):249-256.

3. Rautaharju PM, Wolf HK, Eifler WJ, and Blackburn H. A Simple Procedure for Positioning Precordial ECG and VCG Electrodes Using an Electrode Locator. Journal of Electrocardiology 1976; 9(1):35-40.

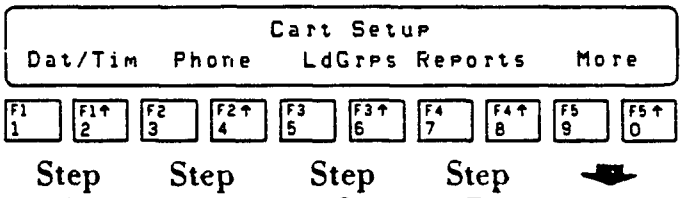
MARQUETTE MAC PC SETUP

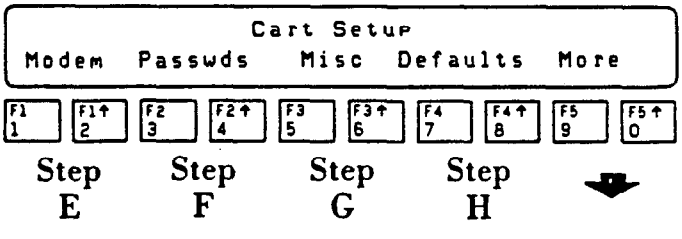
To begin cardiograph setup, press [⏻] to display the *Main Menu*:

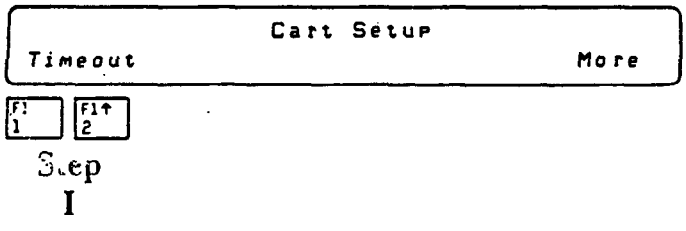


Next press the **SHIFT/ALTERNATE FUNCTION** [⇧] and F1 keys at the same time to display the "System Functions" menu:

Select "Setup" (F2) by pressing either [F2 3] or [F2↑ 4].

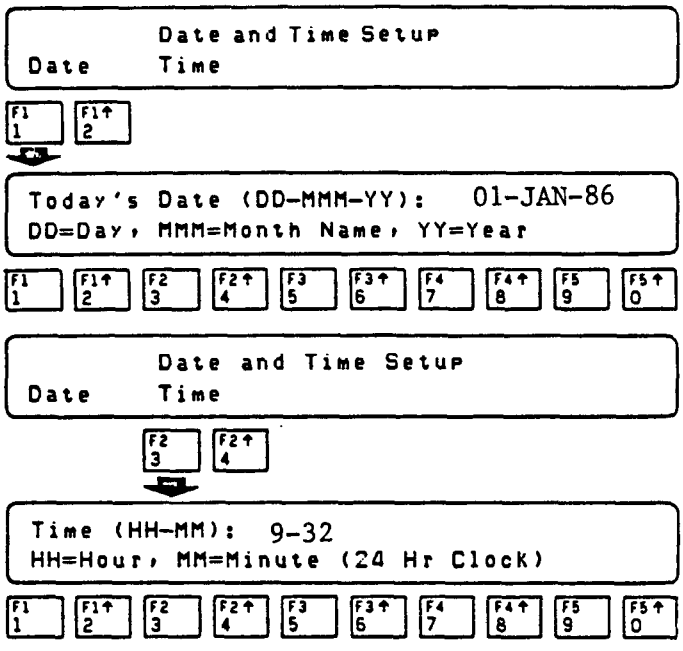






Contents

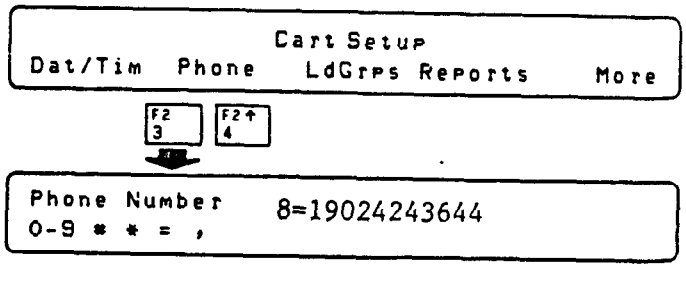
Step A
Date and Time Setup



Press Backspace-delete ⌫ to erase.

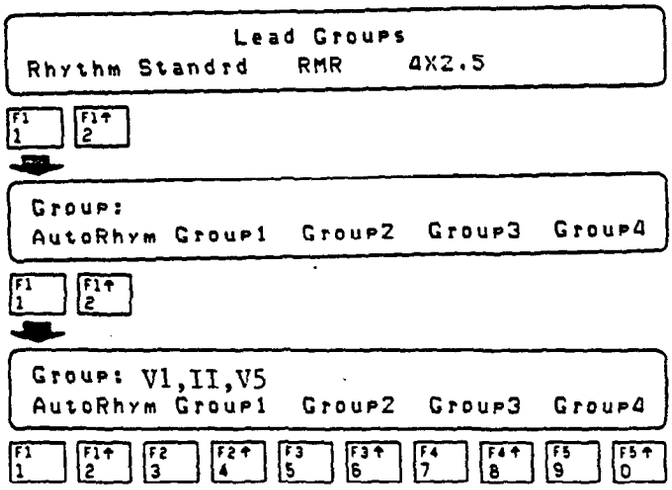
Example: 9-32 is 9:32am
13-15 is 1:15pm

Step B
Phone Setup

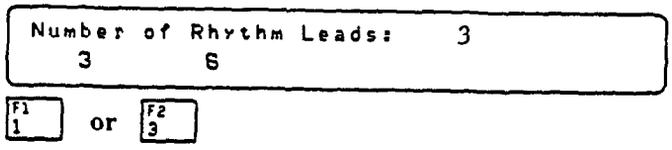


U of Minn. needs 8 to get off campus, you might need 9 or nothing.
"=" gives a pause for off-campus dialtone.
"1" is for long distance.
The rest is Halifax receiving MAC 12, (902) 424-3644.

Step C
Lead Groups — Rhythm Leads Setup



These should never need to be changed.



Step D
Report Formats Setup

```
        Report Formats for:
Confrmd  Unconf
```

F2 3 | F2↑ 4

Do not configure Confirmed.

Press F2 for Unconfirmed.

For each of the following LCDs press either F1 1 (yes) F2 3 (no); and ⇦ to store the report information.

```
Ask for Extra Copies of Plots:      NO
  Yes     No
```

F1 1 | F1↑ 2 | F2 3 | F2↑ 4

Clinic choice here. Some clinics may want extra copies.

```
Suppress Orig Rpt Interpretation: YES
  Yes       No
```

F1 1 | F1↑ 2 | F2 3 | F2↑ 4

Clinic choice here. Marquette interpretation may be printed on ECG. However, the official ARIC interpretation is from Halifax and the Minnesota Coding Center.

```
Suppress Copy Interpretation:      YES
  Yes       No
```

F1 1 | F1↑ 2 | F2 3 | F2↑ 4

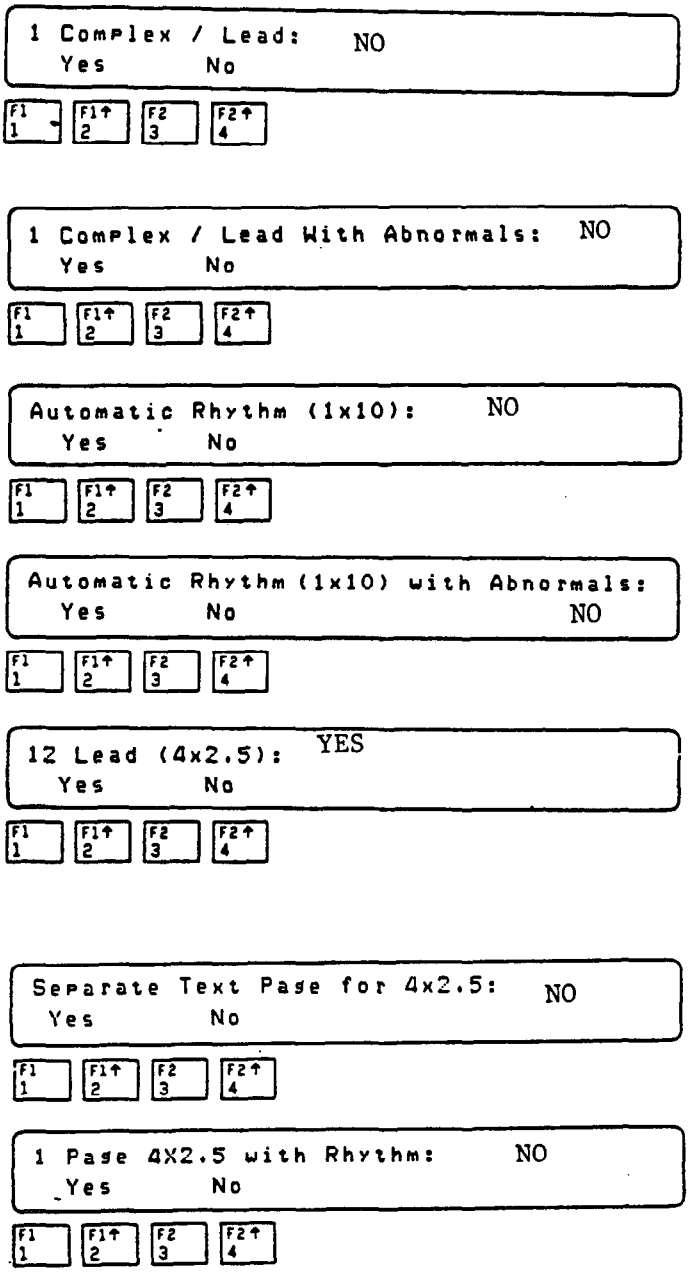
```
Suppress Text Page:  YES
  Yes       No
```

F1 1 | F1↑ 2 | F2 3 | F2↑ 4

```
Rhythm and Morphology Report (RMR): NO
  Yes       No
```

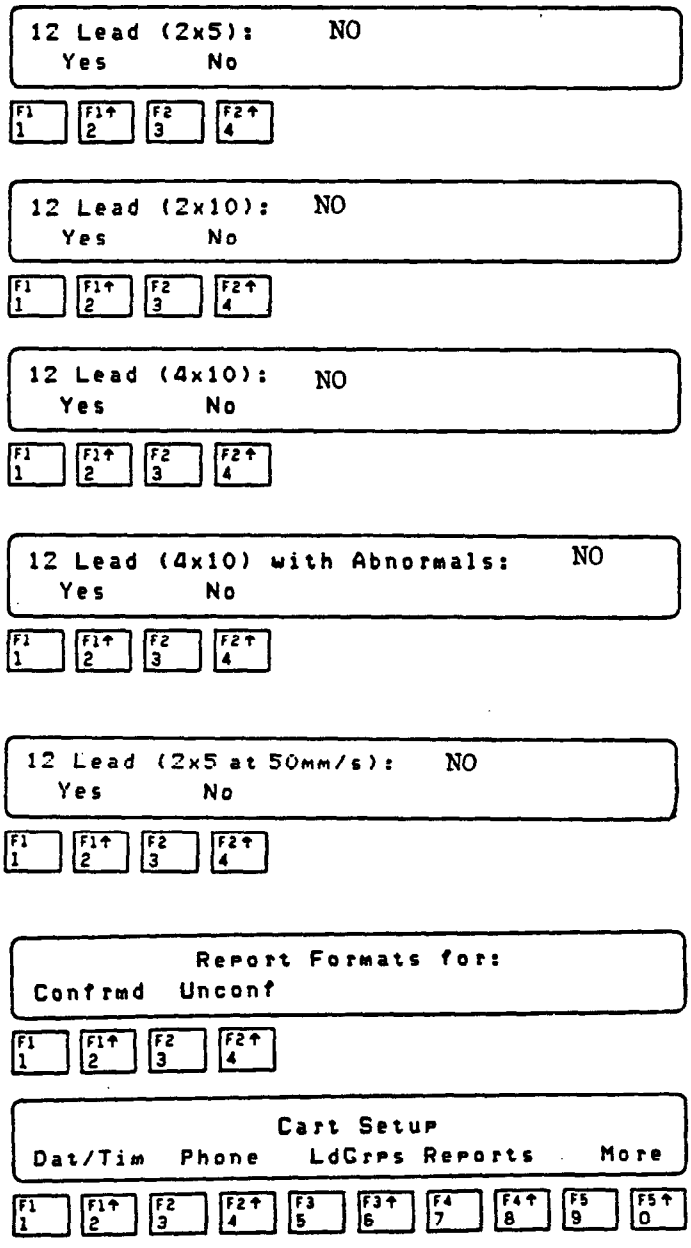
F1 1 | F1↑ 2 | F2 3 | F2↑ 4

Report Formats Setup (Cont)



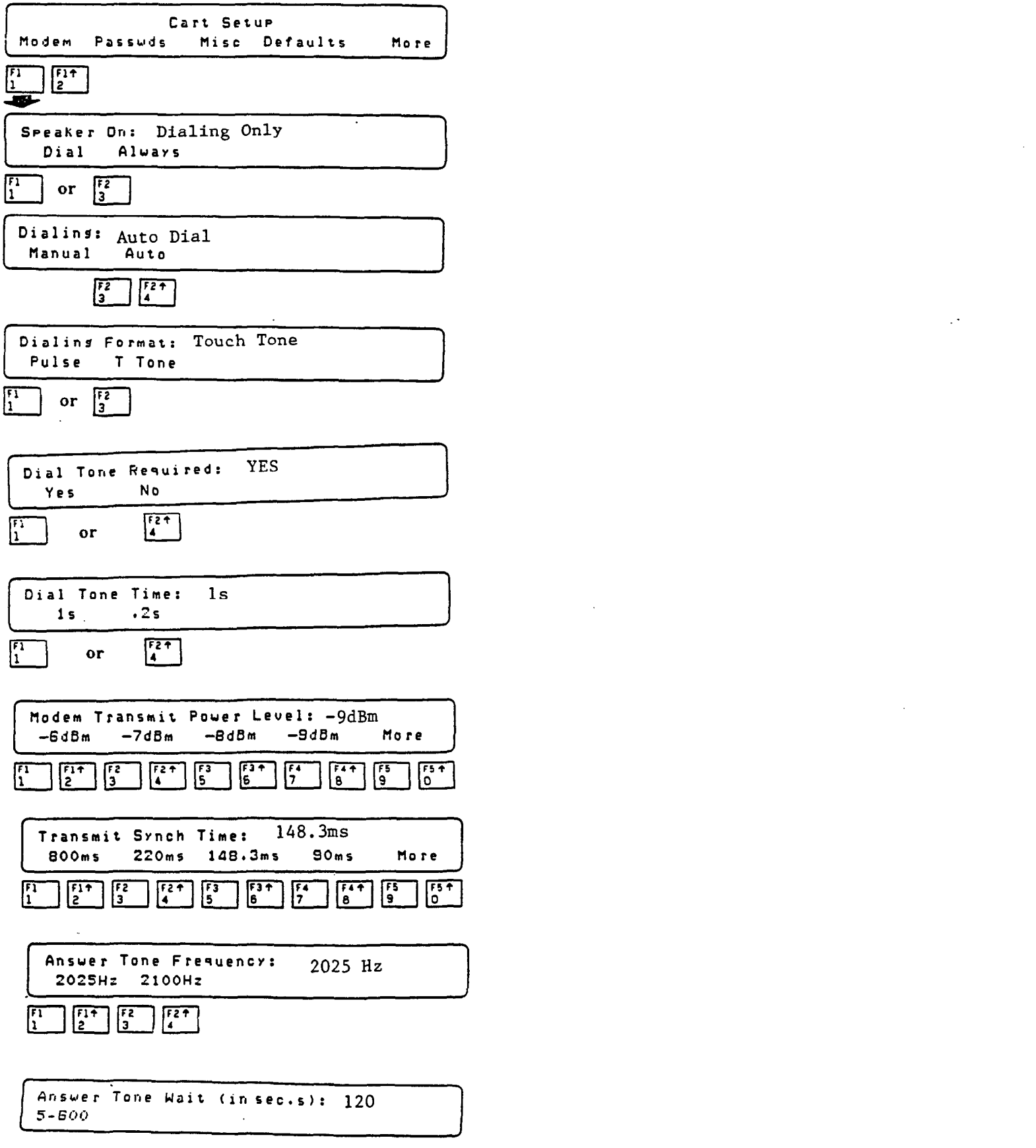
This is the only format to be printed.

Report Formats Setup (Cont)



From here, press Return.

Step E
Modem Setup — Auto Dial



Step F
Passwords

```
Cart Setup
Modem  Passwds  Misc  Defaults  More
```

F2 3 F2↑ 4

Passwords are probably not needed.

```
System Passwords
Level 1 Level 2
```

F1 1 or F2↑ 4

Step G
Miscellaneous Setup

```
Cart Setup
Modem  Passwds  Misc  Defaults  More
```

F3 5 F3↑ 6

For each of the following display prompts, type in the response or press a function (F) key. Then press ⏎ to store that information.

```
Line Frequency:  60 Hz
  60Hz    50Hz
```

F1 1 F1↑ 2 F2 3 F2↑ 4

60 Hz

```
Cart ID:
0-255
```

The cart ID of your ORIGINAL MAC PC is the same as your site ID. If you get a different machine the number MUST BE DIFFERENT. Contact the Minneapolis ECG Center.

```
Site ID:
1-255
```

Site IDs:
Minneapolis ARIC = 5
Forsyth Co. ARIC = 6
Hagerstown ARIC = 7
Jackson ARIC = 8

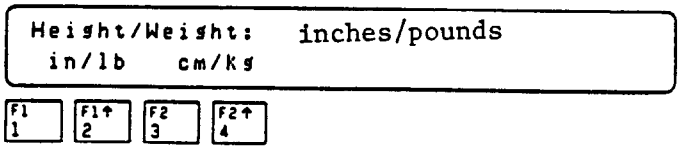
```
Institution Name:
Up to 40 Characters
```

Enter your location and study name. (Only 21 of the 40 characters will show here but that's OK.)

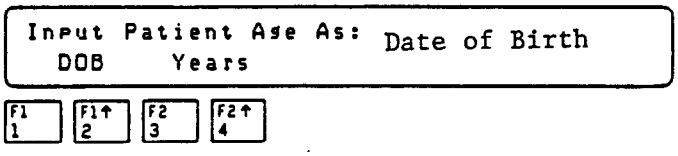
```
Number of Patient ID Digits:  9
1-12
```

9 digits

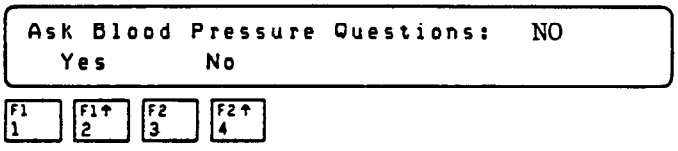
Miscellaneous Setup (Cont)



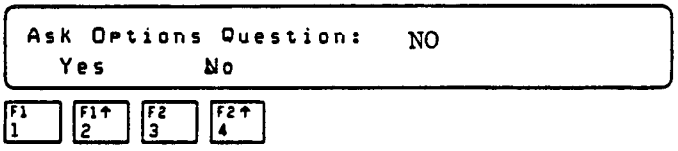
E to V6 measurement in centimeters is entered under Height.



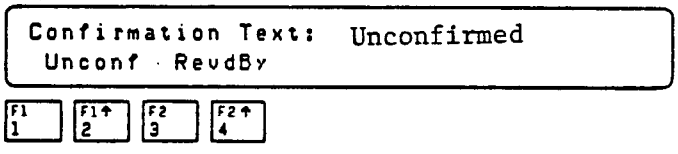
DOB



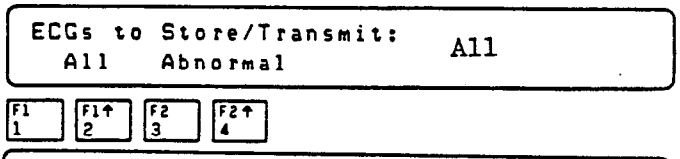
NO



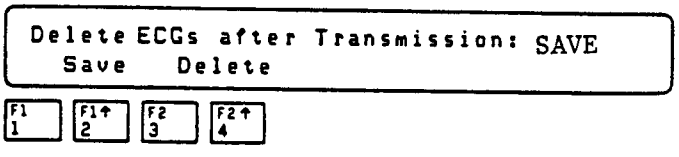
NO



Unconfirmed

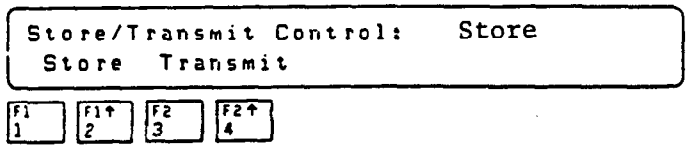


ALL

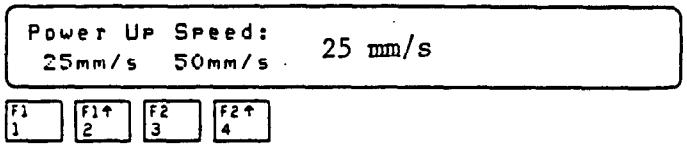


SAVE. It is very important to change this to SAVE. By default the machine deletes ECGs as soon as they are transmitted, without waiting for confirmation from Halifax.

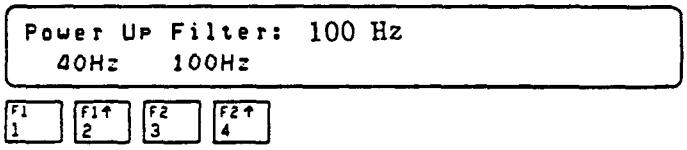
Miscellaneous Setup (Cont)



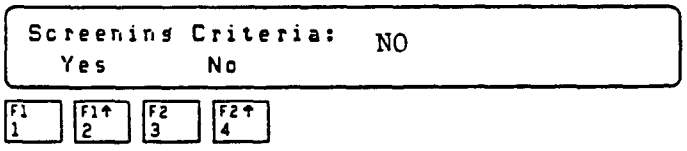
Store



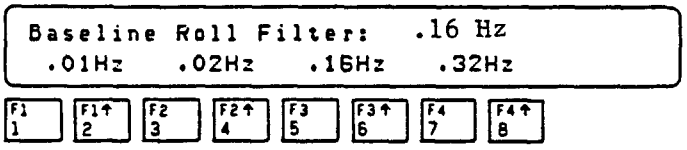
25 mm/s



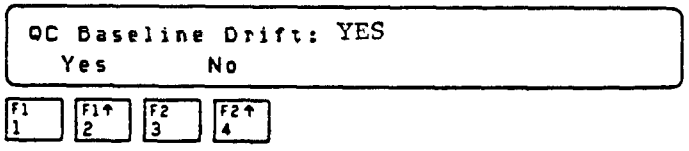
100 Hz



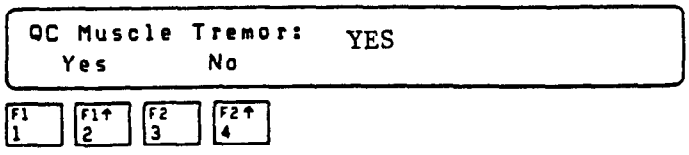
NO



.16 Hz

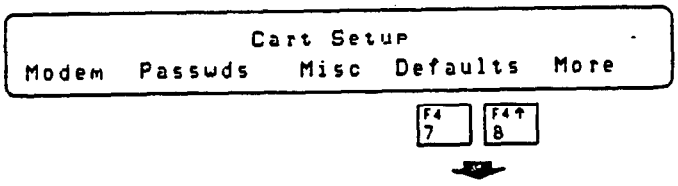


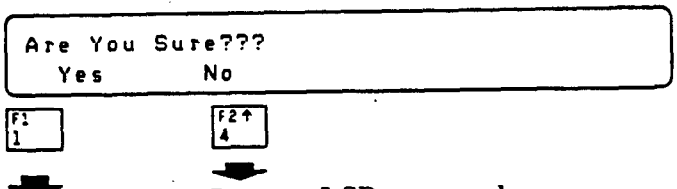
YES



YES

Step H
Defaults Setup



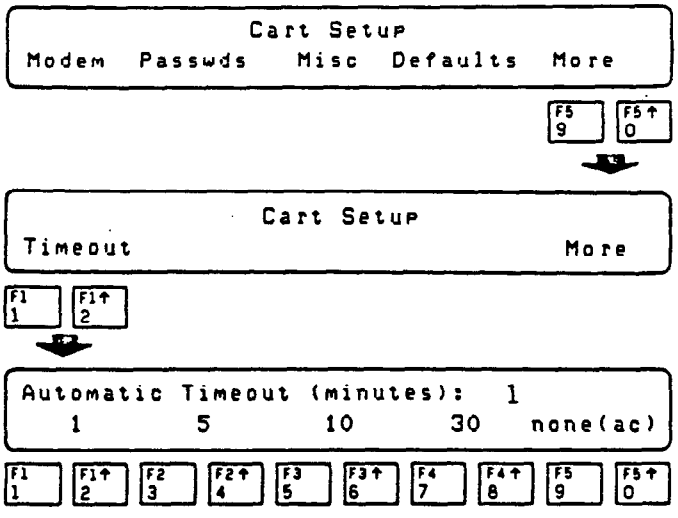


Returns LCD to second **Cart Setup** display.

NEVER say yes to return to original factory setup defaults because that will set the machine to delete ECGs after transmission (see the last window on page 9).

Returns cardiograph to original factory setup defaults. Any cardiograph setup changes since factory defaults will be deleted. Returns LCD to second **Cart Setup** display.

Step I
Timeout



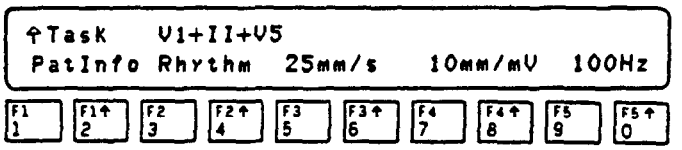
This saves the battery.

"Timeout" is the amount of time it takes for the LCD to go blank when the MAC PC is not being used.

If the "none(ac)" option is selected, the timeout length will be indefinite if and only if a charger (Power Module) is attached to the MAC PC and the battery status (section XII) message indicates "OK" or "FULL". If "none(ac)" is selected and a charger is NOT attached, then the timeout length will be set to 10 minutes.

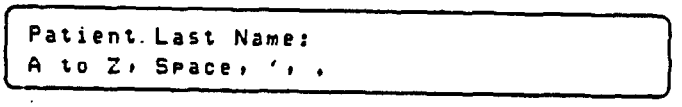
Appendix B

MAC PC ENTRY INFORMATION NEEDED FOR EACH PARTICIPANT

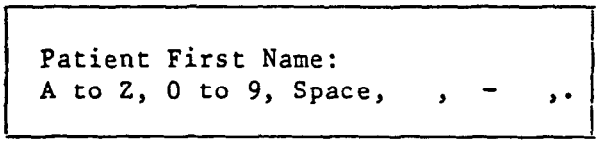


Hit either F1 or F1↑.

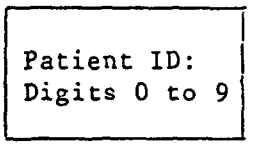
-This won't show up if the machine was just turned on.
-Hit either F1 button if it is a new person.
-Hit either F2 button if you want to correct an entry and/or take another ECG on the same person.



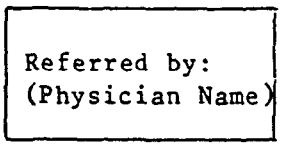
Enter first 4 letters of Last Name:
examples: SMIT, JONE, HESS



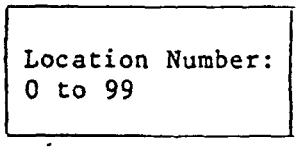
Enter complete ID. ARIC: M123456
TOMHS: M12345SMIT



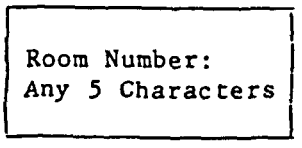
Repeat digit portion of ID.
ARIC: 123456
TOMHS: 12345



Leave blank.
Hit Return.



ARIC: Enter Contact Year (1,2,etc.)
TOMHS: Leave Blank.



Enter your Technician ID number.

TOMHS ONLY

Patient Over 1 Year Old: Yes Yes No	"Yes" is already entered so hit return.
Age: 0 to 127 years	Enter age.

ARIC ONLY

Date of Birth (DD-MMM-YY): DD=Day, MMM=Month Name, YY=Year	To type dash press [⇧] and [-F] at the same time. DD= Day (1-31) MMM= LETTERS of month (JAN., FEB., etc.) YY= Year (86,87,etc.)
Height: 0 to 999 inches	Put in E to V6 distance in cm.
Weight: 0 to 999 lbs.	ARIC: Leave blank Return TOMHS: Enter chest circumference in cm.
Sex: Male Female	Indicate sex, hit either F1 or F2.
Race: Cauc Black Oriental Hisp More	Leave blank. Return
Medication: None Unknown Clr+Add Add Scroll	Leave blank Return

The MAC PC is now ready to take a 12-lead ECG (press [12 ⏦]) or a 3 lead rhythm strip (press [3 ⏦]).

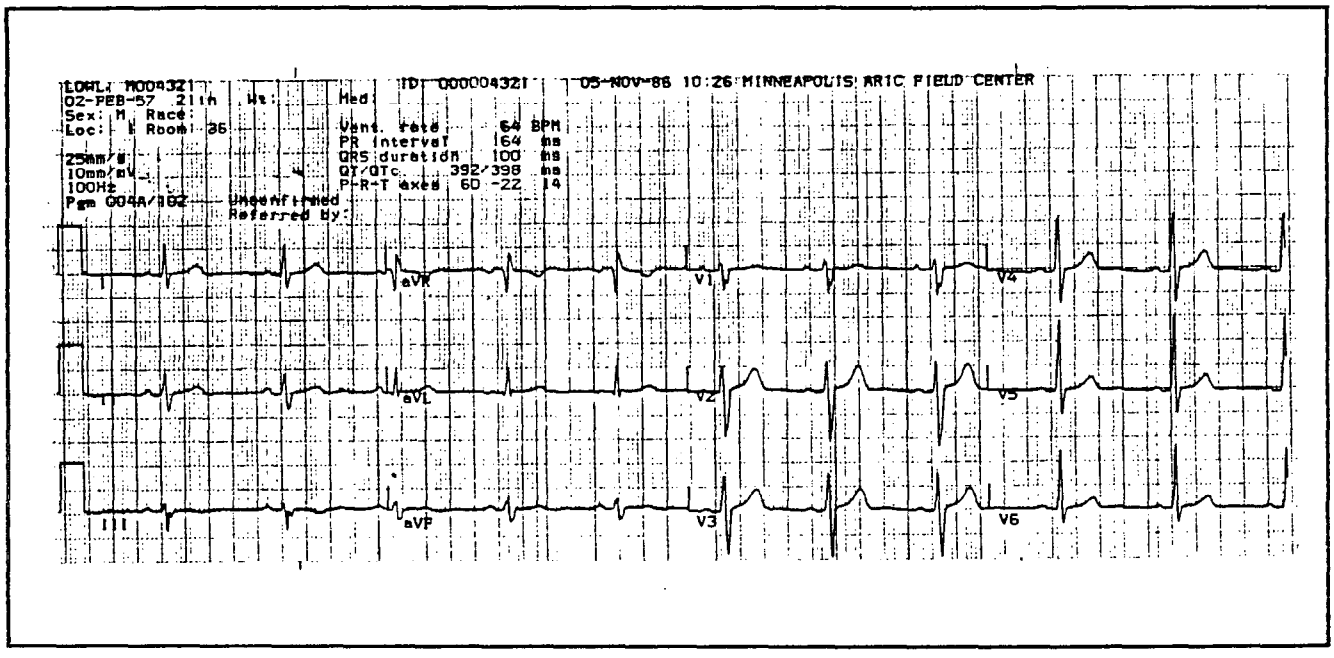
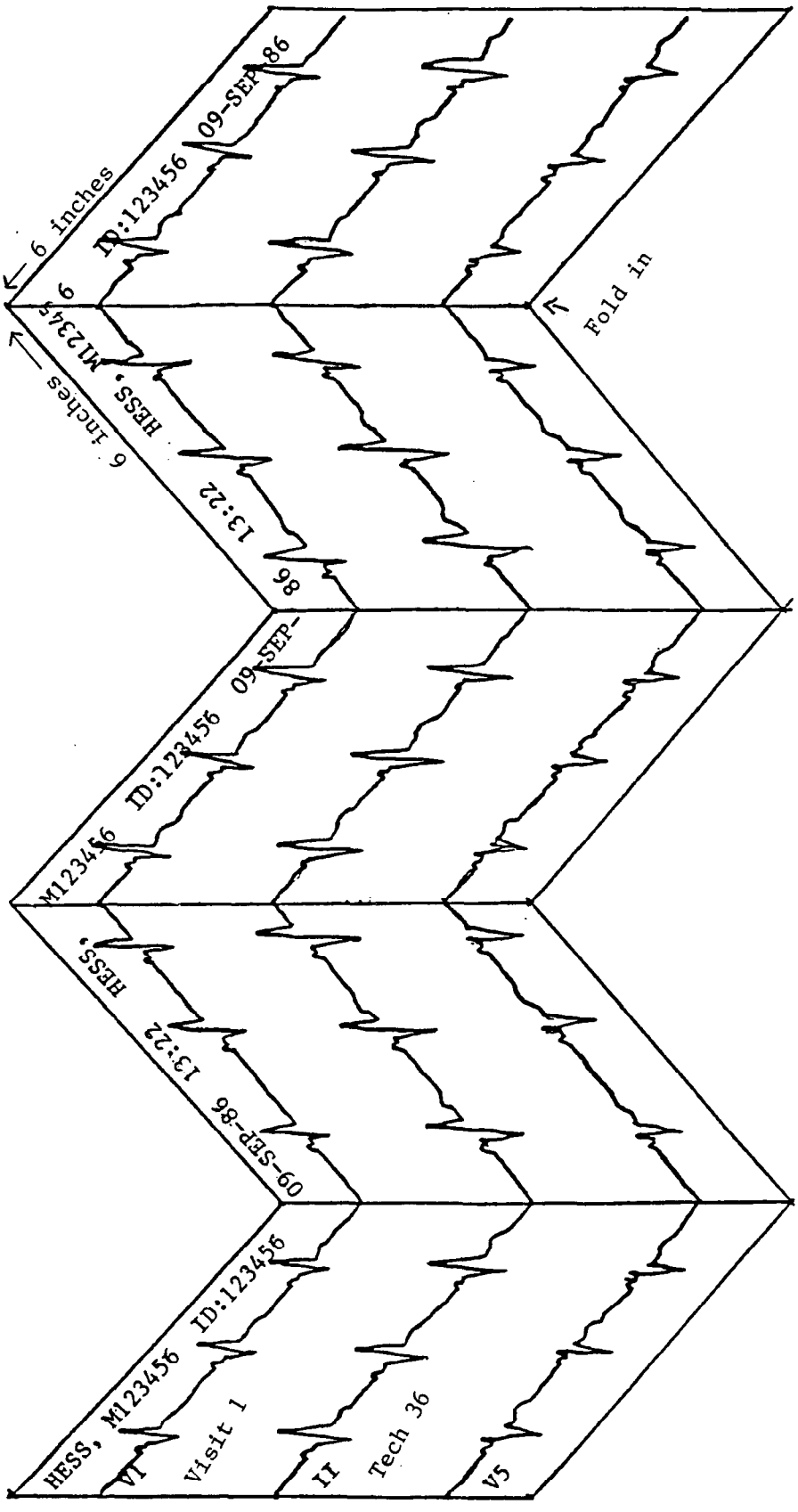


Figure 11. Typical Electrocardiogram Using MAC PC

TWO MINUTE RHYTHM STRIPS MUST BE FOLDED IN THIS MANNER



Appendix

MINNESOTA CODE 1982

Q and QS Patterns

(Do not code in the presence of WPW code 6-4-1.) To qualify as a Q-wave, the deflection should be at least 0.1 mV (1 mm in amplitude).

Anterolateral site (leads I, aVL, V_6)

1-1-1 Q/R amplitude ratio ≥ ⅓, plus Q duration ≥ 0.03 sec in lead I or V_6.
1-1-2 Q duration ≥ 0.04 sec in lead I or V_6.
1-1-3 Q duration ≥ 0.04 sec, plus R amplitude ≥ 3 mm in lead aVL.
1-2-1 Q/R amplitude ratio ≥ ⅓, plus Q duration ≥ 0.02 sec and < 0.03 sec in lead I or V_6.
1-2-2 Q duration ≥ 0.03 sec and < 0.04 sec in lead I or V_6.
1-2-3 QS pattern in lead I. Do not code in the presence of 7-1-1.
1-2-8 Initial R amplitude decreasing to 2 mm or less in every beat (and absence of codes 3-2, 7-1-1, 7-2-1, or 7-3) between V_5 and V_6. (All beats in lead V_5 must have an initial R > 2 mm.)
1-3-1 Q/R amplitude ratio ≥ ⅕ and < ⅓, plus Q duration ≥ 0.02 sec and < 0.03 sec in lead I or V_6.
1-3-3 Q duration ≥ 0.03 sec and < 0.04 sec, plus R amplitude ≥ 3 mm in lead aVL.

Posterior (inferior) site (leads II, III, aVF)

1-1-1 Q/R amplitude ratio ≥ ⅓, plus Q duration ≥ 0.03 sec in lead II.
1-1-2 Q duration ≥ 0.04 sec in lead II.
1-1-4 Q duration ≥ 0.05 sec in lead III, plus a Q-wave amplitude ≥ 1.0 mm in the majority of beats in lead aVF.
1-1-5 Q duration ≥ 0.05 sec in lead aVF.
1-2-1 Q/R amplitude ratio ≥ ⅓, plus Q duration ≥ 0.02 sec and < 0.03 sec in lead II.
1-2-2 Q duration ≥ 0.03 sec and < 0.04 sec in lead II.
1-2-3 QS pattern in lead II. Do not code in the presence of 7-1-1.
1-2-4 Q duration ≥ 0.04 sec and < 0.05 sec in lead III, plus a Q-wave ≥ 1.0 mm amplitude in the majority of beats in aVF.
1-2-5 Q duration ≥ 0.04 sec and < 0.05 sec in lead aVF.
1-2-6 Q amplitude ≥ 5.0 mm in leads III or aVF.
1-3-1 Q/R amplitude ratio ≥ ⅕ and < ⅓, plus Q duration ≥ 0.02 sec and < 0.03 sec in lead II.
1-3-4 Q duration ≥ 0.03 sec and < 0.04 sec in lead III, plus a Q-wave ≥ 1.0 mm amplitude in the majority of beats in lead aVF.
1-3-5 Q duration ≥ 0.03 sec and < 0.04 sec in lead aVF.
1-3-6 QS pattern in each of leads III and aVF. (Do not code in the presence of 7-1-1.)

Anterior site (leads V_1, V_2, V_3, V_4, V_5)

1-1-1 Q/R amplitude ratio ≥ ⅓ plus Q duration ≥ 0.03 sec in any of leads V_2, V_3, V_4, V_5.
1-1-2 Q duration ≥ 0.04 sec in any of leads V_1, V_2, V_3, V_4, V_5.
1-1-6 QS pattern when initial R-wave is present in adjacent lead to the right on the chest, in any of leads V_2, V_3, V_4, V_5, V_6.
1-1-7 QS pattern in all of leads V_1–V_4 or V_1–V_5.

1-2-1 Q/R amplitude ratio ≥ ⅓, plus Q duration ≥ 0.02 sec and < 0.03 sec, in any of leads V_2, V_3, V_4, V_5.

1-2-2 Q duration ≥ 0.03 sec and < 0.04 sec in any of leads V_2, V_3, V_4, V_5.

1-2-7 QS pattern in all of leads V_1, V_2, and V_3. (Do not code in the presence of 7-1-1.)

1-2-8 Initial R amplitude decreasing to 2.0 mm or less in every beat (and absence of codes 3-2, 7-1-1, 7-2-1, or 7-3) between any of leads V_2 and V_3, V_3 and V_4, or V_4 and V_5. (All beats in the lead immediately to the right on the chest must have an initial R > 2 mm.)

1-3-1 Q/R amplitude ratio ≥ ⅓ and < ⅓ plus Q duration ≥ 0.02 sec and < 0.03 sec in any of leads V_2, V_3, V_4, V_5.

1-3-2 QS pattern in lead V_1 and V_2. (Do not code in the presence of 3-1 or 7-1-1.)

QRS Axis Deviation

(Do not code in presence of low-voltage QRS, code 9-1, WPW 6-4-1, ventricular conduction defects, or 7-1-1, 7-2-1, and 7-4.)

2-1 Left. QRS axis from −30° through −90° in leads I, II, III. (The algebraic sum of major positive and major negative QRS waves must be zero or positive in I, negative in III, and zero or negative in II.)

2-2 Right. QRS axis from +120° through −150° in leads I, II, III. (The algebraic sum of major positive and major negative QRS waves must be negative in I, and zero or positive in III, and in I must be one-half or more of that in III.)

2-3 Right (optional code when 2-2 is not present). QRS axis from +90° through +119° in leads I, II, III. (The algebraic sum of major positive and major negative QRS waves must be zero or negative in I and positive in II and III.)

2-4 Extreme axis deviation (usually S1, S2, S3 pattern). QRS axis from −90° through −149° in leads I, II, and III. (The algebraic sum of major positive and major negative QRS waves must be negative in each of leads I, II, and III.)

2-5 Indeterminate axis. QRS axis approximately 90° from the frontal plane. (The algebraic sum of major positive and major negative QRS waves is zero in each of leads I, II and III, or the information from these three leads is incongruous.)

High Amplitude R Waves

3-1 Left: R amplitude > 26 mm in either V_5 or V_6, or R amplitude > 20.0 mm in any of leads I, II, III, aVF, or R amplitude > 12.0 mm in lead aVL measured only on second to last complete normal beat.

3-2 Right: R amplitude ≥ 5.0 mm and R amplitude ≥ S amplitude in the majority of beats in lead V_1, when S amplitude is > R amplitude somewhere to the left on the chest of V_1 (codes 7-3 and 3-2, if criteria for both are present).

3-3 Left (optional code when 3-1 is not present): R amplitude > 15.0 mm but ≤ 20.0 mm in lead I, or R amplitude in V_5 or V_6, plus S amplitude in V_1 > 35.0 mm.

3-4 Criteria for 3-1 and 3-2 both present.

ST Junction (J) and Segment Depression

(Do not code in the presence of codes 6-4-1, 7-1-1, 7-2-1 or 7-4. When 4-1, 4-2, or 4-3 is coded, then a 5-code must also be assigned except in lead V_1.)

Anterolateral site (leads I, aVL, V_6)

4-1-1 STJ depression ≥ 2.0 mm and ST segment horizontal or downward sloping in any of leads I, aVL, or V_6.

4-1-2 STJ depression ≥ 1.0 mm but < 2.0 mm, and ST segment horizontal or downward sloping in any of leads I, aVL, or V_6.

4-2 STJ depression ≥ 0.5 mm and < 1.0 mm and ST segment horizontal or downward sloping in any of leads I, aVL, or V_6.

4-3 No STJ depression as much as 0.5 mm but ST segment downward sloping and segment or T-wave nadir ≥ 0.5 mm below P-R baseline, in any of leads I, aVL, or V_6.

4-4 STJ depression ≥ 1.0 mm and ST segment upward sloping or U-shaped, in any of leads I, aVL, or V_6.

Posterior (inferior) site (leads II, III, aVF)

4-1-1 STJ depression ≥ 2.0 mm and ST segment horizontal or downward sloping in lead II or aVF.

4-1-2 STJ depression ≥ 1.0 mm but < 2.0 mm and ST segment horizontal or downward sloping in lead II or aVF.

4-2 STJ depression ≥ 0.5 mm and < 1.0 mm and ST segment horizontal or downward sloping in lead II or aVF.

4-3 No STJ depression as much as 0.5 mm, but ST segment downward sloping and segment or T-wave nadir ≥ 0.5 mm below P-R baseline in lead II.

4-4 STJ depression ≥ 1.0 mm and ST segment upward sloping, or U-shaped, in lead II.

Anterior site (leads V_1, V_2, V_3, V_4, V_5)

4-1-1 STJ depression ≥ 2.0 and ST segment horizontal or downward sloping in any of leads V_1, V_2, V_3, V_4, V_5.

4-1-2 STJ depression ≥ 1.0 mm but < 2.0 mm and ST segment horizontal or downward sloping in any of leads V_1, V_2, V_3, V_4, V_5.

4-2 STJ depression ≥ 0.5 mm and < 1.0 mm and ST segment horizontal or downward sloping in any of leads V_1, V_2, V_3, V_4, V_5.

4-3 No STJ depression as much as 0.5 mm, but ST segment downward sloping and segment or T-wave nadir ≥ 0.5 mm below P-R baseline in any of leads V_2, V_3, V_4, V_5.

4-4 STJ depression ≥ 1.0 mm and ST segment upward sloping or U-shaped in any of leads V_1, V_2, V_3, V_4, V_5.

T-Wave Items

(Do not code in the presence of codes 6-4-1, 7-1-1, 7-2-1 or 7-4.)

Anterolateral site (leads I, aVL, V_6)

5-1 T amplitude negative 5.0 mm or more in either of leads I, V_6, or in lead aVL when R amplitude is ≥ 5.0 mm.

5-2 T amplitude negative or diphasic (positive-negative or negative-positive type) with negative phase at least 1.0 mm but not as deep as 5.0 mm in lead I or V_6, or in lead aVL when R amplitude is ≥ 5.0 mm.

5-3 T amplitude zero (flat), or negative, or diphasic (negative-positive type only) with less than 1.0 mm negative phase in lead I or V_6, or in lead aVL when R amplitude is ≥ 5.0 mm.

5-4 T amplitude positive and T/R amplitude ratio < 1/20 in any of leads I, aVL, V_6; R wave amplitude must be ≥ 10.0 mm.

Posterior (inferior) site (leads II, III, aVF)

5-1 T amplitude negative 5.0 mm or more in lead II, or in lead aVF when QRS is mainly upright.

5-2 T amplitude negative or diphasic with negative phase (negative-positive or positive-negative type) at least 1.0 mm but not as deep as 5.0 mm in lead II, or in lead aVF when QRS is mainly upright.

5-3 T amplitude zero (flat), or negative, or diphasic (negative-positive type only) with less than 1.0 mm negative phase in lead II; not coded in lead aVF.

5-4 T amplitude positive and T/R amplitude ratio < 1/20 in lead II; R wave amplitude must be ≥ 10.0 mm.

Anterior site (leads V_2, V_3, V_4, V_5)

5-1 T amplitude negative 5.0 mm or more in any of leads V_2, V_3, V_4, V_5.

5-2 T amplitude negative (flat), or diphasic (negative-positive or positive-negative type) with negative phase at least 1.0 mm but not as deep as 5.0 mm, in any of leads V_2, V_3, V_4, V_5.

5-3 T amplitude zero (flat), or negative, or diphasic (negative-positive type only) with less than 1.0 mm negative phase, in any of leads V_3, V_4, V_5.

5-4 T amplitude positive and T/R amplitude ratio < 1/20 in any of leads V_3, V_4, V_5; R wave amplitude must be ≥ 10.0 mm.

A-V Conduction Defect

6-1 Complete (third degree) A-V block (permanent or intermittent) in any lead. Atrial and ventricular complexes independent, and atrial rate faster than ventricular rate, with ventricular rate < 60.

6-2-1 Mobitz Type II (occurrence of P-wave on time with dropped QRS and T).

6-2-2 Partial (second degree) A-V block in any lead (2:1 or 3:1 block).

6-2-3 Wenckebach's Phenomenon (P-R interval increasing from beat to beat until QRS and T dropped).

6-3 P-R (P-Q) interval ≥ 0.22 sec in the majority of beats in any of leads I, II, III, aVL, aVF.

6-4-1 Wolff-Parkinson-White Pattern (WPW), persistent. Sinus P-wave. P-R interval < 0.12 sec, plus QRS duration ≥ 0.12 sec, plus R peak duration ≥ 0.06 sec, coexisting in the same beat and present in the majority of beats in any of leads I, II, aVL, V_4, V_5, V_6. (6-4-1 suppresses 1-2-3, 1-2-7, 1-2-8, 1-3-2, 1-3-6, all 3, 4, 5, 9-2, 9-4, 9-5 codes.)

6-4-2 WPW Pattern, intermittent. WPW pattern in ≤ 50% of beats in appropriate leads.

6-5 Short P-R interval. P-R interval < 0.12 sec in all beats of any two of leads I, II, III, aVL, aVF.

6-6 Intermittent aberrant atrioventricular conduction. P-R > 0.12 sec (except in presence of 6-5 or heart rate greater than 100); wide QRS complex > 0.12 sec; normal P-wave when most beats are sinus rhythm. (Do not code in the presence of 6-4-2.)

6-8 Artificial pacemaker.

Ventricular Conduction Defect

7-1-1 Complete left bundle branch block (LBBB). (Do not code in presence of 6-1, 6-4-1, 6-8, 8-2-1 or 8-2-2.) QRS duration ≥ 0.12 sec in a majority of beats (of the same QRS pattern) in any of leads I, II, III, aVL, aVF, *plus* R peak duration ≥ 0.06 sec in a majority of beats (of the same QRS pattern) in any of leads I, II, aVL, V_5, V_6. (7-1-1 suppresses 1-2-3, 1-2-7, 1-2-8, 1-3-2, 1-3-6, all 2, 3, 4, 5, 9-2, 9-4, 9-5 codes. If any other codable Q-wave coexists with the LBBB pattern, code the Q and diminish the 7-1-1 code to a 7-4 code.)

7-1-2 Intermittent left bundle branch block. Same as 7-1-1 but with presence of normally conducted QRS complexes of different shape than the LBBB pattern.

7-2-1 Complete right bundle branch block (RBBB). (Do not code in the presence of 6-1, 6-4-1, 6-8, 8-2-1 or 8-2-2.) QRS duration ≥ 0.12 sec in a majority of beats (of the same QRS pattern) in any of leads I, II, III, aVL, aVF, *plus:* R′ > R in V_1 or QRS mainly upright, *plus* R peak duration ≥ 0.06 sec in V_1 or V_2; or V_2; or S duration > R duration in all beats in lead I or II. (Suppresses 1-2-8, all 2-, 3-, 4- and 5-codes, 9-2, 9-4, 9-5.)

7-2-2 Intermittent right bundle branch block. Same as 7-2-1 but with presence of normally conducted QRS complexes of different shape than the RBBB pattern.

7-3 Incomplete right bundle branch block. QRS duration < 0.12 sec in each of leads I, II, III, aVL, aVF, and R′ > R in either of leads V_1, V_2 (Code as 3-2 in addition if those criteria are met. 7-3 suppresses code 1-2-8.)

7-4 Intraventricular block. QRS duration ≥ 0.12 sec in a majority of beats in any of leads I, II, III, aVL, aVF. (7-4 suppresses all 2, 3, 4, 5, 9-2, 9-4, 9-5 codes.)

7-5 R-R′ pattern in either of leads V_1, V_2 with R′ amplitude ≤ R.

7-6 Incomplete left bundle branch block. (Do not code in the presence of any codable Q- or QS-wave.) QRS duration ≥ 0.10 sec and < 0.12 sec in the majority of beats of each of leads I, aVL, and V_5 or V_6.

7-7 Left anterior hemiblock (LAH). QRS duration < 0.12 sec in the majority of beats in leads I, II, III, aVL, aVF, plus Q-wave amplitude ≥ 0.25 mm and < 0.03 sec duration in lead I, plus left axis deviation of −45° or more negative. (In presence of 7-2, code 7-8 if axis is < −45° and the Q-wave in lead I meets the above criteria.)

7-8 Combination of 7-7 and 7-2.

Arrhythmias

8-1-1 Presence of frequent atrial or junctional premature beats (10% or more of recorded complexes).

8-1-2 Presence of frequent ventricular premature beats (10% or more of record complexes).

8-1-3 Presence of both atrial and/or junctional premature beats and ventricular premature beats (so that individual frequencies are < 10% but *combined* premature beats are ≥ 10% of complexes).

8-1-4 Wandering atrial pacemaker.

8-1-5 Presence of 8-1-2 and 8-1-4.

8-2-1 Ventricular fibrillation or ventricular asystole.

8-2-2 Persistent ventricular (idioventricular) rhythm.

8-2-3 Intermittent ventricular tachycardia. Three or more consecutive ventricular premature beats occurring at a rate ≥ 100. This includes more persistent ventricular tachycardia.

8-2-4 Ventricular parasystole (should not be coded in presence of 8-3-1).

8-3-1 Atrial fibrillation (persistent).

8-3-2 Atrial flutter (persistent).

8-3-3 Intermittent atrial fibrillation (code if 3 or more clear-cut, consecutive sinus beats are present in any lead).

8-3-4 Intermittent atrial flutter (code if 3 or more clear-cut, consecutive sinus beats are present in any lead).

8-4-1 Supraventricular rhythm persistent. QRS duration < 0.12 sec; and absent P-waves or presence of abnormal P-waves (inverted or flat in aVF); and regular rhythm.

8-4-2 Supraventricular tachycardia intermittent. Three consecutive atrial or junctional premature beats occurring at a rate ≥ 100.

8-5-1 Sinoatrial arrest. Unexpected absence of P, QRS and T, plus a R-R interval at a fixed multiple of the normal interval, ± 10%.

8-5-2 Sinoatrial block. Unexpected absence of P, QRS and T, preceded by progressive shortening of P-P intervals. (R-R interval at a fixed multiple of the normal interval, ± 10%.

8-6-1 A-V dissociation with ventricular pacemaker (without capture). Requires: P-P and R-R occur at variable rates with ventricular rate as fast as or faster than the atrial rate, plus variable P-R intervals, plus no capture beats.

8-6-2 A-V dissociation with ventricular pacemaker (with capture).

8-6-3 A-V dissociation with atrial pacemaker (without capture).

8-6-4 A-V dissociation with atrial pacemaker (with capture).

8-7 Sinus tachycardia (over 100/min).

8-8 Sinus bradycardia (under 50/min).

8-9 Other arrhythmias. Heart rate may be recorded as a continuous variable.

ST Segment Elevation

Anterolateral site (leads I, aVL, V_6)

9-2 ST segment elevation ≥ 1.0 mm in any of leads I, aVL, V_6.

Posterior (inferior) site (leads II, III, aVF)

9-2 ST segment elevation ≥ 1.0 mm in any of leads II, III, aVF.

Anterior site (leads V_1, V_2, V_3, V_4, V_5)

9-2 ST segment elevation ≥ 1.0 mm in lead V_5 or ST segment elevation ≥ 2.0 mm in any of leads V_1, V_2, V_3, V_4.

Miscellaneous Items

9-1 Low QRS amplitude. QRS peak-to-peak amplitude < 5 mm in all beats in each of leads I, II, III, or < 10 mm in all beats in each of leads V_1, V_2, V_3, V_4, V_5, V_6. (Check calibration before coding.)

9-3 P-wave amplitude ≥ 2.5 mm in any of leads II, III, aVF, in a majority of beats.

9-4-1 QRS transition zone at V_3 or to the right of V_3 on the chest. (Do not code in the presence of 6-4-1, 7-1-1, 7-2-1 or 7-4.)

9-4-2 QRS transition zone at V_4 or to the left of V_4 on the chest. (Do not code in the presence of 6-4-1, 7-1-1, 7-2-1 or 7-4.)

9-5 T-wave amplitude > 12 mm in any of leads I, II, III, aVL, aVF, V_1, V_2, V_3, V_4, V_5, V_6. (Do not code in the presence of 6-4-1, 7-1-1, 7-2-1 or 7-4.)

9-8-1 Technical problems which interfere with coding.

9-8-2 Technical problems which do not interfere with coding.

Incompatible Codes

The codes in the left column suppress codes in the right column.

Code	Suppresses this code(s)
All Q-, QS-codes	7-6
Q > 0.03 in lead I	7-7
3-1	1-3-2
3-2	1-2-8, 7-3
6-1	All other codes except 8-2
6-4-1	All other codes
6-8	All other codes
7-1-1	1-2-3, 1-2-7, 1-2-8, 1-3-2, 1-3-6, all 2-, 3-, 4-, and 5-codes, 7-7, 9-2, 9-4, 9-5
7-2-1	1-2-8, all 2-, 3-, 4-, and 5-codes, 9-2, 9-4, 9-5
7-3	1-2-8
7-4	All 2-, 3-, 4-, and 5-codes, 9-2, 9-4, 9-5
8-1-2	8-2-4
8-1-4	8-1-1, 9-3
8-2-1	All other codes
8-2-2	All other codes
8-2-3	8-1-2
8-3-1	8-1-1, 8-1-2
8-3-2	6-2-2, 8-1-1, 8-1-2
8-3-3	8-1-1, 8-1-2
8-3-4	6-2-2
8-4-1	6-5
8-4-1 + heart rate ⩾ 140	All other codes except 7-4 or 6-2
Heart rate > 100	6-5
8-4-2	8-1-1
9-1	All 2-codes

Performance Grade Levels

PERFORMANCE GRADE LEVEL	NOISE μvrms	DRIFT	
		Overall (mV)	Beat to Beat (μV) Rest
1	≤30	≤0.7	≤190
2	≤60	≤0.8	≤250
3	≤90	≤0.9	≤310
4	≤120	≤1.0	≤370
5	>120	>1.0	>370

Data Record

Position	Length	Contents	Assigned By
1-7	7	Subject ID in format ANNNNNC	ARIC Clinic
8-12	5	Blank filled	
13-15	3	ECG (ECG data record)	ARIC CC
16-16	1	A (Form version)	ARIC CC
17-17	1	D (Record type)	ARIC CC
18-19	2	03 (Study code)	ARIC CC
20-21	2	14 (Form code)	ARIC CC
22-22	1	Blank	
23-24	2	Contact Year, blank filled right justified	ARIC Clinic
25-42	18	Blank filled	
43-44	2	00 first time record processed. Incremented by one for new processing at Hfx (in case new version of processing programs)	Hfx
45-52	8	Date of creation of record in format MM/DD/YY	Hfx
53-57	5	Time of creation of record in format HH:MM	Hfx
58-60	3	Operator Code in ASCII (Blank)	Hfx
61-68	8	Date that record was updated in format MM/DD/YY Blank if not relevant	Hfx
69-73	5	Time that record was updated in format HH:MM Blank if not relevant	Hfx
74-74	1	A if new record to be added to database, C if change in record	Hfx
75-76	2	Diskette number (00)	Hfx
77-77	1	Blank	
78-83	6	Numeric sequence # of record in batch	Hfx
84-84	1	Blank	
85-86	2	Site Number	ARIC Clinic
87-87	1	Blank	
88-99	12	ID number	ARIC Clinic
100-100	1	Blank	

Data Record

Position	Length	Contents	Assigned By
101-142	42	Subject Name, Last,First as received from MAC12 ECG cart	
143-143	1	Blank	
144-145	2	Location Code	ARIC Clinic
146-146	1	Blank	
147-148	2	Cart Code	ARIC Clinic
149-149	1	Blank	
150-166	17	Recording Date and Time	
167-167	1	Blank	
168-168	1	Quality grade 1-5	Hfx
169-169	1	Blank	
170-171	2	Minnesota Code L1	Hfx
172-172	1	Blank	
173-174	2	Minnesota Code F1	Hfx
175-175	1	Blank	
176-177	2	Minnesota Code V1	Hfx
178-178	1	Blank	
179-180	2	Minnesota Code L4	Hfx
181-181	1	Blank	
182-183	2	Minnesota Code F4	Hfx
184-184	1	Blank	
185-186	2	Minnesota Code V4	Hfx
187-187	1	Blank	
188-189	2	Minnesota Code L5	Hfx
190-190	1	Blank	
191-192	2	Minnesota Code F5	Hfx
193-193	1	Blank	
194-195	2	Minnesota Code V5	Hfx
196-196	1	Blank	
197-198	2	Minnesota Code L92	Hfx
199-199	1	Blank	

Data Record

Position	Length	Contents	Assigned By
200-201	2	Minnesota Code F92	Hfx
202-202	1	Blank	
203-204	2	Minnesota Code V92	Hfx
205-205	1	Blank	
206-207	2	Minnesota Code C2	Hfx
208-208	1	Blank	
209-210	2	Minnesota Code C3	Hfx
211-211	1	Blank	
212-213	2	Minnesota Code C6	Hfx
214-214	1	Blank	
215-216	2	Minnesota Code C7	Hfx
217-217	1	Blank	
218-219	2	Minnesota Code C91	Hfx
220-220	1	Blank	
221-222	2	Minnesota Code C93	Hfx
223-223	1	Blank	
224-225	2	Minnesota Code C94	Hfx
226-226	1	Blank	
227-228	2	Minnesota Code C95	Hfx
229-229	1	Blank	
230-231	2	Minnesota Code E7	Hfx
232-232	1	Blank	
233-234	2	CR LF	

ECG REPORT RECORD FORMAT

ITEM	LENGTH	
1	7	ID number.
2	4	Calibration - lead I
3	4	- lead II
4	4	- lead III
5	4	- lead AVR
6	4	- lead AVL
7	4	- lead AVF
8	4	- lead V1
9	4	- lead V2
10	4	- lead V3
11	4	- lead V4
12	4	- lead V5
13	4	- lead V6
14	1	Lead reject flag I
15	1	II
16	1	III
17	1	AVR
18	1	AVL
19	1	AVF
20	1	V1
21	1	V2
22	1	V3
23	1	V4
24	1	V5
25	1	V6
26	3	Noise value for lead I
27	3	(source data) II
28	3	III
29	3	AVR
30	3	AVL
31	3	AVF
32	3	V1
33	3	V2
34	3	V3
35	3	V4
36	3	V5
37	3	V6
38	3	Noise value for lead I
39	3	(average complex) II
40	3	III
41	3	AVR
42	3	AVL
43	3	AVF
44	3	V1
45	3	V2
46	3	V3
47	3	V4
48	3	V5
49	3	V6

ECG REPORT RECORD FORMAT

EM	LENGTH			
50	3	Beat to beat drift	I	
51	3	values for lead	II	
52	3		III	
53	3		AVR	
54	3		AVL	
55	3		AVF	
56	3		V1	
57	3		V2	
58	3		V3	
59	3		V4	
60	3		V5	
61	3		V6	
62	3	Residual drift	I	
63	3	values for lead	II	
64	3	(average complex)	III	
65	3		AVR	
66	3		AVL	
67	3		AVF	
68	3		V1	
69	3		V2	
70	3		V3	
71	3		V4	
72	3		V5	
73	3		V6	
74	3	Heart rate		
75	4	P axis		
76	4	QRS axis		
77	4	T axis		
78	2	Minnesota codes	L1	Automated Minnesota Code for all cohort ECGs
79	2		F1	
80	2		V1	
81	2		L4	
82	2		F4	
83	2		V4	
84	2		L5	
85	2		F5	
86	2		V5	
87	2		L92	
88	2		F92	
89	2		V92	
90	2		C2	
91	2		C3	
92	2		C6	
93	2		C7	
94	2		C91	
95	2		C93	
96	2		C94	
97	2		C95	
98	2		E7	
99	4	CIIS value		Cardiac Injury Score, based on published prognostic studies

ECG REPORT RECORD FORMAT

ITEM	LENGTH		
100	4	P amplitude	I
101	4	positive	II
102	4		III
103	4		AVR
104	4		AVL
105	4		AVF
106	4		V1
107	4		V2
108	4		V3
109	4		V4
110	4		V5
111	4		V6
112	4	P amplitude	I
113	4	negative	II
114	4		III
115	4		AVR
116	4		AVL
117	4		AVF
118	4		V1
119	4		V2
120	4		V3
121	4		V4
122	4		V5
123	4		V6
124	3	P duration	I
125	3		II
126	3		III
127	3		AVR
128	3		AVL
129	3		AVF
130	3		V1
131	3		V2
132	3		V3
133	3		V4
134	3		V5
135	3		V6
136	4	Q amplitude	I
137	4		II
138	4		III
139	4		AVR
140	4		AVL
141	4		AVF
142	4		V1
143	4		V2
144	4		V3
145	4		V4
146	4		V5
147	4		V6

ECG REPORT RECORD FORMAT

ITEM	LENGTH		
148	3	Q duration	I
149	3		II
150	3		III
151	3		AVR
152	3		AVL
153	3		AVF
154	3		V1
155	3		V2
156	3		V3
157	3		V4
158	3		V5
159	3		V6
160	4	R amplitude	I
161	4		II
162	4		III
163	4		AVR
164	4		AVL
165	4		AVF
166	4		V1
167	4		V2
168	4		V3
169	4		V4
170	4		V5
171	4		V6
172	3	R duration	I
173	3		II
174	3		III
175	3		AVR
176	3		AVL
177	3		AVF
178	3		V1
179	3		V2
180	3		V3
181	3		V4
182	3		V5
183	3		V6
184	4	S amplitude	I
185	4		II
186	4		III
187	4		AVR
188	4		AVL
189	4		AVF
190	4		V1
191	4		V2
192	4		V3
193	4		V4
194	4		V5
195	4		V6

ECG REPORT RECORD FORMAT

ITEM	LENGTH		
196	3	S duration	I
197	3		II
198	3		III
199	3		AVR
200	3		AVL
201	3		AVF
202	3		V1
203	3		V2
204	3		V3
205	3		V4
206	3		V5
207	3		V6
208	4	R' amplitude	I
209	4		II
210	4		III
211	4		AVR
212	4		AVL
213	4		AVF
214	4		V1
215	4		V2
216	4		V3
217	4		V4
218	4		V5
219	4		V6
220	3	R' duration	I
221	3		II
222	3		III
223	3		AVR
224	3		AVL
225	3		AVF
226	3		V1
227	3		V2
228	3		V3
229	3		V4
230	3		V5
231	3		V6
232	4	J amplitude	I
233	4		II
234	4		III
235	4		AVR
236	4		AVL
237	4		AVF
238	4		V1
239	4		V2
240	4		V3
241	4		V4
242	4		V5
243	4		V6

ECG REPORT RECORD FORMAT

ITEM	LENGTH		
244	5	Tneg amplitude	I
245	5		II
246	5		III
247	5		AVR
248	5		AVL
249	5		AVF
250	5		V1
251	5		V2
252	5		V3
253	5		V4
254	5		V5
255	5		V6
256	5	Tpos amplitude	I
257	5		II
258	5		III
259	5		AVR
260	5		AVL
261	5		AVF
262	5		V1
263	5		V2
264	5		V3
265	5		V4
266	5		V5
267	5		V6
268	3	P-R interval	
269	3	Q-T interval	
270	3	J-T interval	
271	3	QRS interval	
272	3	HEIGHT	
273	3	WEIGHT	
274	2	AGE	
275	1	SEX	
276	1	RACE	
277	3	Dalhousie Score for LV mass estimate based on extensive independent echo documentation	

Also: R-peak activation time
Measurement of U-wave

ABSTRACT REPRODUCTION FORM

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13th International Congress on Electrocardiology
27th International Symposium on Vectorcardiography
Washington, D.C., U.S.A.
September 10–12, 1986

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AN ELECTROCARDIOGRAPHIC MODEL FOR PREDICTION OF LEFT VENTRICULAR MASS

Hermann K. Wolf, James W. Warren, Pentti M. Rautaharju, John A. Milliken, Eldon R. Smith, Ted E. Cuddy, Dept. Physiology and Biophysics, Dalhousie University, Halifax, N.S. Canada.

Left ventricular mass (LVM) has been shown to be an important independent predictor of cardiovascular mortality and there is considerable interest in the estimation of LVM from ECG, both for clinical and epidemiological applications. We evaluated the accuracy of LVM prediction using ECG's of 480 patients with echocardiograms recorded within one week. The age range was 16 to 90 years, 263 were women. The echocardiograms were measured by a trained technician and reviewed by an experienced cardiologist. The ECG's were processed by computer and a set of selected ECG and demographic parameters were used in a stepwise regression procedure to predict LVM and LVM/surface area (LVMI). The traditional Estes score predicted LVMI with R**2 .24. This prediction was improved to R**2 .50 by addition of age, TV1, RaVL+SV3, and SV1+RV5 as continuous variables. A marginally better prediction (R**2 .53) was achieved for LVM by a simpler equation using age, sex, RaVL, TV1, and RV5+SV1. It is concluded that an LVH score derived from age, sex and simple ECG measurements can predict LVM with a reasonable accuracy and considerably better than traditional criteria for LVH.

AUTHOR'S SIGNATURE Hermann Wolf DATE March 28, 1986

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YOUNG INVESTIGATOR'S AWARD

The first author requests that this abstract be considered for the Young Investigator's Award. The first author certifies that the results are based on original research. Further, the first author certifies to being less than 40 years of age.

Author's Signature_____ Date_____

Left Ventricular Mass Index
Dalhousie Criteria

Best ECG Predictors for Males

1. QRS Duration
2. R amplitude in V5
3. S amplitude in III
4. S amplitude in V4
5. ST slope in V6
6. Negative T depth in V5

$R^2 = 0.65$

$r = 0.81$ › with respect to Echo LVMI

Cardiac Infarction Injury Score: An Electrocardiographic Coding Scheme for Ischemic Heart Disease

P. M. RAUTAHARJU, M.D., PH.D., J. W. WARREN, B.SC., U. JAIN, PH.D., H. K. WOLF, PH.D., AND C. L. NIELSEN, B.SC.

Circulation, Vol 64, No 2, August 1981

Cardiac Infarction Injury Score: An Electrocardiographic Coding Scheme for Ischemic Heart Disease

P. M. RAUTAHARJU, M.D., PH.D., J. W. WARREN, B.SC., U. JAIN, PH.D., H. K. WOLF, PH.D., AND C. L. NIELSEN, B.SC.

SUMMARY **A multivariate decision-theoretic electrocardiogram (ECG) classification scheme called Cardiac Infarction Injury Score (CIIS) was developed using ECGs of 387 patients with myocardial infarction (MI) and 320 subjects without infarction. The most accurate and stable classification was achieved by using a combination of eight binary (single threshold), three ternary (two thresholds), and four ECG features measured on a continuous scale. For practical visual coding of ECGs, the CIIS coding procedure uses a checklist containing 12 items measured from the conventional 12-lead ECG.**

The CIIS test results indicate that, in comparison with conventional ECG criteria for MI used in clinical trials, the diagnostic accuracy can be considerably improved by optimizing feature and threshold selection and by multivariate analysis. The CIIS detected MI with a sensitivity of 85% and a specificity of 95%. Using a higher severity level, a specificity of 99% was achieved, with a sensitivity of 71%. One of the primary uses of the CIIS is coding of significant worsening of the ECG with new coronary events from annually recorded ECGs in clinical trials and epidemiologic studies.

RELIABLE DETECTION of myocardial infarction at periodic follow-up examinations and reliable identification of the progression or regression of cardiac involvement in hypertension are major concerns in epidemiologic studies and clinical trials aimed at preventing heart disease. Although improved noninvasive techniques may replace or supplement electrocardiography in detecting and grading the severity of left ventricular hypertrophy in hypertension, the ECG remains the most important tool for detecting and classifying myocardial infarction.

The Minnesota Code[1] has become the most widely used ECG classification system in epidemiologic studies, and its application significantly improved standardization of ECG measurements. The Minnesota Code is a hierarchical, decision-tree type of ECG classifier that was developed by determining upper normal limits for univariate or bivariate distributions of selected ECG features, particularly in the design of category 1 of the code (Q, QS waves and related items). Problems are encountered with this approach if many features are used in classification criteria. When the Minnesota Code was developed, statistical computer techniques were not in general use and the criteria (features and thresholds) were selected more or less intuitively, causing two major problems: first, the feature selection and the thresholds are not optimal and the sensitivity of the criteria tends to be low; second, the use of a decision-tree structure results in a considerable degree of classification instability[2, 3] whereby a single error can easily result in misclassification.

The Cardiac Infarction Injury Score (CIIS) scheme was developed to improve the accuracy and stability of ECG classification in ischemic heart disease. The CIIS classifier uses a set of 11 discrete (binary and ternary) ECG features in combination with four features measured in continuum and uses a simple scoring scheme suitable for both visual and computer classification of the conventional 12-lead ECG.

Methods

ECG Data Files Used for Program Design and Testing

The data file used to design CIIS was composed of the ECGs of 387 patients with myocardial infarction and 320 subjects without clinical evidence of infarction (table 1). The criteria for infarction were based on non-ECG evidence in the acute phase, including prolonged, typical cardiac ischemic chest pain not relieved by nitroglycerin, and a peak CPK enzyme level more than 85% above the upper normal limit for the hospital. The noninfarct group consisted of 145 subjects with documented hypertension of over 1 year's duration (diastolic pressure 90 mm Hg or higher) but without any clinical evidence of myocardial infarction and 175 ostensibly healthy subjects with a normal blood pressure. The age range for the patients with myocardial infarction was 30–76 years, (median 58 years). The age range for the noninfarct group was 19–75 (median 42 years).

The source data used in ECG analysis were composed of digital tapes acquired at a sampling rate of 500 samples/sec per channel. The overall frequency band of the data acquisition system was 0.05–125 Hz (lower and upper 3 db points).

Two-thirds of the ECG data file was randomly assigned to the design (training) set and the remaining third was retained to test the accuracy of the CIIS

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Supported in part by the Nova Scotia Heart Foundation and the Medical Research Council of Canada (SDG-2) and NHRDP grants 603-1052-45 and 6603-20-10-54. The testing of the CIIS program was performed in part pursuant to NHLBI contract 1-HV-42911.

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TABLE 1. *Groups Used to Develop the Cardiac Infarction Injury Score Classifier*

Groups	n
Myocardial infarction	
Less than 1 week	151
One week to 1 month	39
One month to 1 year	105
More than 1 year	92
Total	387
Noninfarction	
Hypertensive patients	145
Normal subjects	175
Total	320

classifier (table 2). After test results were obtained on this independent test subgroup, the final refinement of the thresholds and the determination of the coefficients for the linear discriminant function were performed using the whole data file.

The repeatability of the CIIS was tested in a different group of 139 male subjects, ages 35–57 years, in whom the ECG was rerecorded within 8 weeks from the first ECG. These subjects had no clinical evidence of myocardial infarction, but about one-third of them had hypertension. These subjects were recalled for an exercise test and had no clinical events in the interim period. This test group was used to assess normal confidence limits of CIIS changes (table 3) when coding events signaling significant worsening of the ECG in serial ECG comparison.

Statistical Methods

Feature Selection

The initial set of ECG features used to develop CIIS contained a set of 32 logic criteria for myocardial infarction used in the Minnesota Code[1] and a supplementary set of variables listed in table 4. Initial test runs revealed, however, that both the features used and the thresholds assigned to the Minnesota Code variables were suboptimal and these features rarely, if ever, entered into the best set of 14 for the infarction vs noninfarction classifier. Therefore, the logic criteria of the Minnesota Code were rejected and the search was limited to the variables listed in table 4.

The first 10 features of table 4 were used as both discrete and continuous variables. The procedures used for feature "discretization" have been described.[3] These procedures aim at optimizing the threshold selection either at binary (a single threshold) or ternary level (high and low threshold) to maximize the classification accuracy. The feature selection was done by the conventional forward sequential selection ("step-up") algorithm using the Mahalanobis distance[4] as the optimization criterion. In instances when the binary and the ternary level "discretization" yielded equal performance, the lowest quantization level (i.e., binary) was retained.

For calculation of the Mahalanobis distance and the linear discriminant function, the Gauss-Jordan method of matrix inversion described by Orden[5] was used with double-precision (64-bit) arithmetic.

Selection of Lead and Format for CIIS

The CIIS was designed for the conventional 12-lead ECG. For feature selection (such as the Q-wave duration), two "redundant" leads were also used: the inverted aV_R ($-aV_R$) and the inverted aV_L ($-aV_L$) lead. These inverted leads fall into a smooth, continuous logical pattern sequence within other conventional frontal plane leads.[6, 7] The initial R wave in aV_L turned out to contain diagnostic information usually ignored by current ECG classification criteria. This information is presented in a more familiar form as a Q wave in the inverted lead $-aV_L$. Similarly, the R and

TABLE 2. *Diagnostic Accuracy of the Cardiac Infarction Injury Score Classifier*

Feature set	Design file SP (%)	Design file SE (%)	Design file AI (%)	Test file SP (%)	Test file SE (%)	Test file AI (%)
A. Discrete features	90	95	85	87	93	80
	96	93	89	93	89	82
	98	82	80	95	82	77
	100	62	62	99	58	57
B. Continuous features	90	93	83	88	92	80
	96	88	84	94	86	80
	98	85	83	97	85	82
	100	62	62	99	60	59
C. Mixed discrete and continuous features	90	97	87	89	94	83
	96	94	90	93	92	85
	98	88	86	95	85	80
	100	71	71	99	71	70

The classifier discriminant score was adjusted to yield a specificity of 90, 96, 98 and 100% in the design set.

Abbreviations: SP = specificity (fraction of correctly classified true negatives [i.e., noninfarcts]); SE = sensitivity (fraction of correctly classified true positives [i.e., infarcts]); AI = association index (SP + SE − 100).

TABLE 3. *Simplified Cardiac Infarction Injury Score (CIIS) Classifier for Practical Visual Coding of Electrocardiograms*

Component	Lead	Feature	Threshold	score
1	aV_L	Q duration in seconds (measured to nearest threshold)	Q absent	5
			0.010	1
			0.020	3
			0.030	9
			0.040	10
			0.050	12
2	aV_L	T amplitude in mm If T negative add 2 points for each mm	≤ 0.5 or ≥ 3	3
			2	
3	$-aV_R$	R amplitude in mm = R (subtract 1 point for each mm)	−1	−R
4	$-aV_R$	T amplitude (positive phase) in mm. Subtract 2 additional points for each mm exceeding 4	0	6
			1	3
			2	0
			3	−2
			4	−5
5	II, aV_F	Largest Q:R amplitude ratio	$\geq 1/20$	12
6	III, $-aV_L$	Largest Q duration in seconds	≥ 0.040	5
7	III	T amplitude (negative phase) in mm	>1	5
8	V_1	T amplitude (positive phase) in mm	>2	5
9	V_2	R amplitude in mm	<3 or ≥ 14	5
10	V_2	T amplitude (negative phase) in mm	$\geq ¼$	5
11	V_3	Q:R amplitude ratio	$>1/20$	9
12	V_5	S amplitude in mm	<2	5

The amplitudes are measured in standard millimeters (1 mm = 0.1mV). Absolute values of negative amplitudes are used. The T amplitude (positive and negative phase) is measured as the absolute value of the largest deflection above and below the PR baseline in a window spanning from 80 msec after the end of QRS to the end of T (see appendix).

CIIS severity levels: level A, CIIS 20, probable injury; level B, CIIS 15, possible injury; level C, CIIS 10, borderline abnormality.

T waves in $-aV_R$ appeared to improve the diagnostic accuracy of the classifier.

In the course of the CIIS development efforts, it also became apparent that the grouping of ECG leads for the Minnesota Code and other clinical ECG classification criteria is suboptimal. The same thresholds and logic criteria are traditionally used for diverse groups of leads, such as I, aV_L, V_6 (lateral), II, III, aV_F (inferior) and V_1 to V_5 (anterior), even though the directions of the lead vectors of the leads in each group may differ widely. In the CIIS, only ECG leads that had a spatial angle less than 20° between their lead vectors were grouped together, i.e., I and V_6, II and aV_F, III and $-aV_L$. The largest value of a given amplitude and duration in each pair was chosen for analysis. The remaining 7 leads were used individually (aV_L, $-aV_R$, V_1, V_2, V_3, V_4 and V_5).

TABLE 4. *Electrocardiographic Features used to Select the Best Variables for the Cardiac Infarction Injury Score Classifier*

Features measured from 10 leads or lead sets

1. Q-wave duration
2. Q-wave amplitude
3. Q/R amplitude ratio
4. R-wave amplitude
5. S-wave amplitude
6. R/S amplitude ratio
7. J-point amplitude
8. ST amplitude 80 msec past J point
9. T-wave amplitude
10. T/R amplitude ratio

Single measurements from frontal plane leads

11. QRS frontal plane axis
12. QRS duration
13. QT/RR interval ratio

Each of the first 10 features of table 4 were measured from 10 leads or lead groups, yielding 100 features. Features 11, 12 and 13 (table 4) increased the total set of variables to 103. In the final refinement of the CIIS classifier (table 5), positive and negative portions of the T wave (whenever biphasic) were treated as separate variables to simplify the logic for visual coding.

Results

Extensive empirical studies during the development of the CIIS indicated that the best feature subsets were usually obtained when the feature selection was done on the continuous rather than the discrete features, particularly when a high level of specificity was desired.[8, 9] Therefore, we chose the feature set for CIIS using the features listed in table 4 as continuous variables. It turned out that the discrete features chosen this way perform about as well as the continuous features (table 2). However, a further improvement at a high level of specificity is achieved by using a combination of continuous and discrete features (set C of table 2).

Table 5 gives the coefficients of the linear discriminant function for the CIIS with 15 combined discrete and continuous features. Three of the features appear both as continuous and discrete variables (1 and 10, 6 and 11, 8 and 12, respectively), because unequal, nonlinear weights in different feature regions can occasionally improve classification accuracy.

Although continuous features are usually awkward in visual ECG coding, the scoring scheme was simplified by incorporating the four continuous features within the structure of the discrete features (table 3). There are 12 steps in this scoring scheme: five involve T-wave measurements, four involve Q-wave durations or Q:R amplitude ratios, two involve the R-wave amplitude and one involves the S-wave amplitude.

TABLE 5. *The Cardiac Infarction Injury Score Classifier with Eight Binary, Three Ternary and Four Continuous Features*

Feature	Lead	Quantization level	Weight
1. T amplitude (positive phase) (μV)	$-aV_R$	Continuous	−0.0262
2. Largest Q:R amplitude ratio	II, aV_F	Binary	11.55 if ≥ 0.18 0 if < 0.18
3. Q:R amplitude ratio	V_3	Binary	8.46 if > 0.06 0 if ≤ 0.06
4. R amplitude (μV)	$-aV_R$	Continuous	−0.0093
5. S amplitude (μV)	V_5	Binary	5.50 if < 183
6. T amplitude (negative phase) (μV)	aV_L	Continuous	0.0244
7. R amplitude	V_2	Ternary	4.76 if < 302 or > 1398 0 otherwise
8. Q duration (msec)	aV_L	Ternary	4.83 if 0 or ≥ 28 0 otherwise
9. T amplitude (negative phase) (μV)	III	Binary	6.63 if > 98 0 otherwise
10. T amplitude (positive phase) (μV)	$-aV_R$	Binary	5.72 if < 146 0 if ≥ 146
11. T amplitude (positive phase) (μV)	aV_L	Ternary	3.10 if ≤ 52 or > 272
12. Q duration (msec)	aV_L	Continuous	0.1330
13. Largest Q duration (msec)	III, $-aV_L$	Binary	4.50 if ≥ 40 0 if < 40
14. T positive amplitude (μV)	V_1	Binary	3.91 if ≥ 240 0 if < 240
15. T amplitude (negative phase) (μV)	V_2	Binary	5.08 if ≥ 20 0 if < 20

Each discrete (binary or ternary) feature contributes to the total score according to its weight for specified ranges of feature values. The weight coefficient of a continuous feature is multiplied by its measured value and the product is added to (or subtracted from) the score. The features are listed in the order in which they were selected into the linear discriminant function in the sequential step-up procedure.

The T- and R-wave amplitudes of the inverted lead $-aV_R$ played a surprisingly prominent role in selection of features for the CIIS classifier, always ranking very high among the best features and their combinations in the linear discriminant. In table 5, the features are listed in the order they were selected to the best discriminating combination, whereas in table 3, the features are grouped according to the logical sequence of frontal and horizontal plane leads.

CIIS Severity Levels

In practical applications, it is often desirable to "discretize" the continuous index such as the CIIS at two or three levels of confidence or the likelihood of the abnormality. The severity levels for CIIS in table 3 were adjusted so that specificity levels of 90%, 96% and 98% were consistently maintained both for the design and the test sets. The validity of these limits was further investigated in 139 subjects in whom the recording was repeated within 8 weeks after the first ECG, with no evidence of coronary events in the interim period. A worsening of the CIIS exceeding 10 points was observed in 4% and a worsening exceeding 20 points in 1% of the subjects. It thus seems plausible to propose these same CIIS severity levels at least tentatively for coding of significant worsening of the ECG in serial comparison of successive annually recorded ECGs in clinical trials.

CIIS Performance According to the Age and Location of Infarct

We estimated the extent to which the accuracy of the CIIS depends on the age and the anatomic location of the infarct (table 6) and found that the age of the infarct influences the accuracy less than expected. The CIIS performs best on infarcts that are 1 week to 1 month old. However, even in patients whose infarct is more than 1 year old, the sensitivity remains at 80% for the 98% specificity level. The CIIS performance is fairly uniform for lateral, anterior and posterior locations of the infarct. As expected, the performance is worse whenever visual classification of the postevent record regarding the location was uncertain.

Figure 1 is a sample ECG tracing illustrating the CIIS coding procedure following the sequence of items in table 3. More detailed guidelines are given in appendix 1. Figure 2 is a second example of ECG features contributing to CIIS in an old infarction classified in the acute phase as posterior-diaphragmatic.

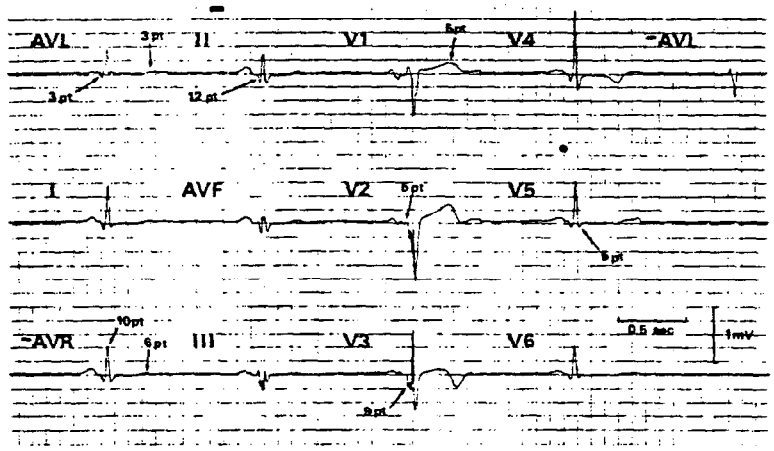

FIGURE 1. *A sample tracing illustrating the Cardiac Infarction Injury Score. Frontal plane leads are organized to facilitate visual coding. The numbers with arrows indicate various components (table 3) that contribute to the total injury score. See appendix 1.*

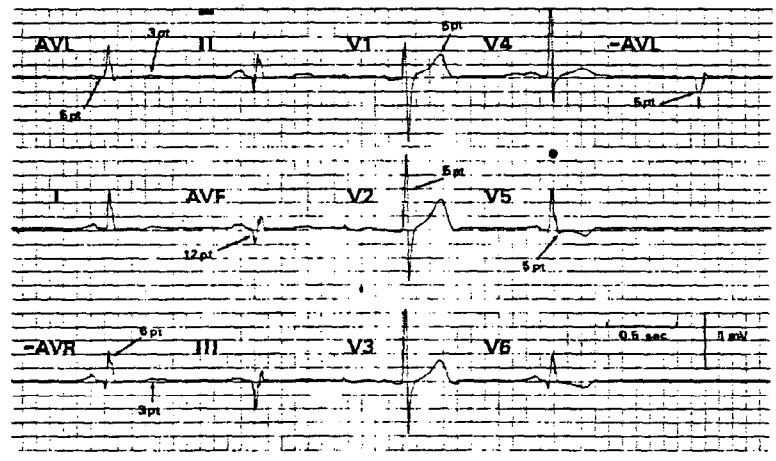

FIGURE 2. *Features contributing to an abnormal Cardiac Infarction Injury Score in old posterodiaphragmatic myocardial infarction. A Q wave in aV_F contributes 12 points to the total score. Other contributions come from aV_L (absent Q, T less than 0.5 mm), $-aV_R$ (flat T), $-aV_L$ (Q greater than 40 msec), V_1 (positive T), V_2 (R amplitude 14 mm) and V_6 (S amplitude less than 2 mm). The amplitude and time scales have been expanded (1 mV = 20 mm and 1 second = 50 mm).*

Discussion

In this study, we show that the classification accuracy of the conventional 12-lead ECG can be substantially improved by improved feature selection and proper optimization of the thresholds of discrete features. The results show that there are ECG features with important diagnostic information for detection of MI that are usually not used in conventional MI criteria. Among these new features are small R and a tall T wave in the inverted aV_R lead, an absent Q in aV_L, a large T or a negative T in aV_L, a negative T in III, a positive T in V_1 and a missing S wave in V_6. The relative contribution to CIIS by these features from different leads probably depends on the location of the injury, but should be studied further.

TABLE 6. *The Sensitivity (%) of the Cardiac Infarction Injury Score According to the Age and Location of the Infarct*

Age or location of infarct	No. of subjects	CIIS ≥ 15 (%)	CIIS ≥ 20 (%)
Less than 1 week	102	95	85
One week to 1 month	57	100	100
One month to 1 year	109	89	80
More than 1 year	99	91	80
Lateral	23	95	90
Posterior/inferior	153	97	95
Anterior	122	98	95
Other*	110	75	60

*Location indeterminable from postevent records.

The age was determined from the onset of the acute phase event. The location of the infarct was judged according to the leads involved in the postevent ECG (lateral = I, aV_L, V_6; posterior/inferior = II, III, aV_F; anterior = V_1 to V_5). The CIIS severity levels 15 and 20 correspond to the estimated specificity of 95% and 98%, respectively.

CIIS = Cardiac Infarction Injury Score.

The CIIS differs fundamentally from other classification schemes currently used in epidemiologic and clinical applications. Most ECG criteria for myocardial infarction, such as those contained in the Minnesota Code[1] or the IBM ECG analysis program developed by Bonner et al.,[10] are based on a sequential, Boolean-type decision tree. Such classification schemes have become popular probably because they are simple, and can be easily learned and adapted to visual coding of ECGs.[11] Optimization of a decision-tree classifier is a difficult statistical problem[12, 13] and unquestionably, the Minnesota Code and other current ECG coding systems are far from optimal.

Like the Minnesota Code, the CIIS scheme uses a set of binary and ternary criteria that can be applied in succession step by step. However, unlike the

Minnesota Code, the CIIS scheme is not based on a "yes/no" decision at any given node of the decision tree. Instead the outcome of each decision contributes in a weighted proportion to the final score. This decision-theoretic approach improves classification stability. In test runs reported earlier,[3] incorrect representation of one feature resulted in a change in infarct/noninfarct classification on the average in slightly over 10% of the records. In contrast, one error at any node of a decision-tree classifier can easily lead to a complete misclassification.[2]

Unlike the commonly used decision-tree ECG classifiers, which tend to favor unconditional yes/no and infarct/noninfarct outcomes from classification, the CIIS expresses the likelihood of an infarction on a continuous scale. The continuous distributions of CIIS in each study group can improve the statistical power of detecting differential trends in study populations, for instance, between treatment groups in clinical heart disease intervention and prevention trials. To simplify the use of CIIS, it may be helpful in many practical applications to use the discrete features of CIIS (table 3), which also apply for changes of CIIS in case of serial comparison of annual ECGs.

The CIIS belongs to a family of statistical classifiers sometimes characterized as decision-theoretic. The best known decision-theoretic ECG classification program is the Bayesian-type multivariate program developed by Pipberger et al.[14] for Frank-lead ECG. The decision-theoretic classifiers, sometimes called second-generation ECG programs,[15] have not gained widespread acceptance for a variety of reasons, even though theoretically they should improve the accuracy of classification.[16] Unquestionably, the unfamiliarity of potential users with the Frank-lead system and the vectorcardiographic features used has delayed the acceptance of the second-generation ECG programs. Conceptual difficulties encountered by the uninitiated with the probabilistic Bayesian statistical approach have confounded these problems, particularly regarding proper use of prior probabilities, which is mandatory for optimal classification. The CIIS coding system combines the simplicity of the first-generation ECG classification schemes with the statistical power and stability achieved by the second-generation ECG programs. These advantages should facilitate the use and acceptance of CIIS.

The grouping of ECG leads in the CIIS scheme differs substantially from that in the Minnesota Code. The Minnesota Code has three groups of leads: I, aV_L and V_6, II, III and aV_F, and V_1 to V_5. We found that the statistical distributions of durations and amplitudes of many ECG features could be considerably narrowed both in the infarct and noninfarct groups by avoiding combinations of leads that differ widely in the orientation and strength of their lead vectors.

The diagnostic accuracy of a classification system depends on the prevalence of infarcts in the population.[17] Two groups of investigators can reach markedly different conclusions on diagnostic accuracy of a classifier even when both groups use identical criteria to select their test groups. This apparent paradox can occur if there are large prevalence differences in the populations from which the test groups are chosen.[18]

For a Bayesian-type second-generation computer-ECG program, the classification accuracy can be maximized by matching the prior probabilities to the expected prevalence of different conditions in the specific population in which the classifier is used. With the CIIS scheme, an equivalent adjustment is achieved by the use of graded severity levels. In clinical populations with a high prevalence of infarcts, a CIIS level of 10 acceptably classifies a given record as an infarct, whereas in populations with a very low prevalence of infarcts, a CIIS level of 20 or higher score would be more appropriate.

An 85% sensitivity for detecting myocardial infarctions in the test group with 95% specificity (i.e., 5% false positives) and a 71% sensitivity with 99% specificity is an encouraging sign of the practicality of the CIIS.

We included the hypertensive patients with the normal subjects in the pooled noninfarct group because hypertensive subjects are an important subgroup in many clinical trials and epidemiologic studies. Hypertensive subjects frequently have ECG changes that may considerably complicate the design of a classifier with high specificity and adequate sensitivity. The performance of a classifier designed only to separate normal subjects from patients with infarcts is unrealistic and misleading in a practical application.

It is not possible from the present study to determine how well the CIIS can identify the anatomic location of the infarct, because no ECG-independent data on the location were available from the acute phase. The division into three groups according to the location was made arbitrarily from the postevent rather than from the acute phase record. An investigation is needed to examine how the different CIIS components from different leads or lead groups can best be used to identify the location of the infarct.

Changing electrocardiographic recording technology can significantly alter the validity of any ECG criteria for myocardial infarction; for instance, by altering the width of the baseline of paper tracings used for visual ECG coding.[19] This fact must be considered when using the CIIS scheme, even though it should prove relatively resistant to minor aberrations in the fidelity or quality of the records.

Appendix 1 presents detailed practical considerations regarding the definitions, measurement and coding rules for CIIS. Perhaps the most significant departure from the Minnesota Code is that the amplitude threshold for "codable" waves is 25 μV instead of 100 μV. The measurement rules for CIIS call for a systematic use of the majority rule when beat-to-beat deviations are observed in the quantities measured. In computer-based coding, a representative complex derived on the basis of selective averaging or a median value of the values measured from normally conducted complexes offers an effective alternative.

All amplitude measurements for CIIS are per-

formed with respect to the PR baseline. The scoring criteria may not be valid if TP baseline is used. In our experience, there are many ambiguities in the Minnesota Code definitions for ST- and T-wave measurements. To avoid these logistic problems in ECG coding, the CIIS defines T-wave amplitudes, for its positive and negative phase, as the absolute values of the largest positive and negative deflections in a window extending from 80 msec after the end of QRS to the end of T. This definition is easy to implement for visual and computer coding, and reflects the contribution of ST to the CIIS in the acute phase of infarction when the distinction between ST and T becomes obscure.

The CIIS coding scheme is being evaluated in several large clinical trials to determine its prognostic value and its value in detecting differential trends in treatment groups as a quantitative measure of the effectiveness of intervention. Initial test runs with the visual CIIS coding scheme indicate that with relatively little practice, a technician can code more than 20 ECGs an hour by using a printed coding sheet containing a checklist of CIIS items.

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Appendix
Measurement and Coding Guidelines for the Cardiac Infarction Injury Score

General Considerations

The writing characteristics of the direct-writing electrocardiograph can substantially influence electrocardiographic measurements.[19] Of particular concern is the baseline width with pressurized ink recorders, which can produce a bias in ECG wave durations. The baseline width produced by a round recording stylus of uniform thickness should be less than 0.2 mm if a paper speed of 50 m/sec is used.[19] The electrocardiograph should meet the minimal specifications established by the ECG committee of the American Heart Association.[20]

The measurement and coding rules specified here differ from commonly used conventions such as those established for the Minnesota Code.[1, 21] For CIIS, "codable" waves are defined using a higher resolution than in the past. In general, a wave with an amplitude 25 μV (0.025 mV) or more is recognized as a codable wave. Microprocessors and computers are increasingly used for ECG acquisition and preprocessing and it would be feasible to provide, even for visual coding, a display format with much better resolution than 25 μV. However, because the standardization of the voltage scale at 10 mm for 1 mV is still common practice, the 25-μV threshold corresponding to ¼ mm on the conventional ECG scale seems a practical compromise at this time.

Another difference is that the CIIS scheme follows the majority rule with exceptions. Complexes with artifacts or excessive noise interfering with measurement are omitted from consideration regarding the majority rule. If computer preprocessing or totally automated processing facilities are available, a suitable alternative for the majority rule is the use of the median value of measurements done on a beat-by-beat basis, or a representative averaged

complex derived after clustering of all complexes found for a given lead or lead group, followed by alignment and selective averaging of complexes.[22]

The CIIS coding scheme is not hierarchical like the Minnesota Code. This implies that each of the 15 components of the CIIS is evaluated separately and independently. All ECG interval measurements and identification of time reference points, such as the beginning and the end of the QRS complex, should be performed from at least three simultaneously recorded, time-coherent ECGs.

Definition of Codable Waves

The reference potential or the *baseline* for all amplitude measurements without exception is the PR segment immediately preceding the earliest part of the QRS complex.

First wave within the QRS complex is the earliest deflection, positive or negative, 25 μV or more in amplitude regardless of its duration.

The first wave is an *initial R wave* if it is positive, and a Q wave if it is negative. (For CIIS coding, no distinction is made between Q and QS waves).

Second wave within QRS is a deflection exceeding 25 μV in amplitude with a sign opposite to that of the first wave within QRS. Subsequent waves within QRS, positive and negative, with alternating signs, are defined similarly.

R amplitude is the amplitude of the highest positive wave within QRS.

S amplitude is the absolute value of the most negative wave within the QRS after an R wave.

QR ratio is measured as the ratio of the absolute amplitudes of Q and R waves. A pattern with a QS wave is considered to have an infinite QR ratio.

J amplitude is the signed value of the ST segment at the end of the QRS complex.

ST amplitude is the signed value of the ST segment 80 msec past the end of the QRS complex.

Positive T amplitude is the highest amplitude of the positive portion of the ST-T complex measured in the window extending from 80 msec past the J point to the end of the T wave.

Negative T amplitude is the absolute value of the most negative part of the ST-T complex measured in the window 80 msec past the J point to the end of the T wave.

The sample tracing in figure 1 illustrates various steps involved in CIIS following the sequence given in table 3.

(1) *Q wave duration in lead aV_L.* Measure Q wave duration to nearest 10 msec. In this record, the Q duration is 20 msec. Check 3 points on the coding form of table 3. The absence of the Q wave in aV_L scores 5 points (i.e., no initial negative deflection ¼ mm or more in amplitude.

(2) *T-wave amplitude in aV_L.* Three points are added to the score if no positive portion of the T wave is 0.5 mm or more or if any portion of the T wave is 3 mm or more. The time window for measurement of T amplitude extends from 80 msec past the end of QRS (4 mm at a paper speed of 50 mm/second) to the end of the T wave. In the sample tracing (fig. 1), the T wave is flat, i.e., less than 0.5 mm. The score is 3 points. (If the T in aV_L were negative, 2 more points would be added to the score for each millimeter of negative amplitude.)

(3) *R amplitude in the inverted aV_R lead.* In the conventional aV_R lead, this item can be measured as the amplitude of the most negative deflection within QRS complex (a Q, S or QS wave). One point is subtracted for each millimeter of R-wave amplitude in the inverted aV_R lead ($-aV_R$) in our sample tracing the R wave is 10 mm, and 10 points are subtracted from the score.

(4) *T amplitude (positive phase) in $-aV_R$.* A flat or small T wave in $-aV_R$ lead adds to the score and a tall T wave subtracts from the score. In our case, the most positive deflection in the T window is clearly less than 0.5 mm, and six points are added. If the conventional (noninverted) aV_R lead is used, the absolute amplitude of the negative portion of the T wave is measured under this item.

(5) *Q:S amplitude ratio in leads II and aV_F.* A Q wave 5% or more of the R wave in *either* lead adds 12 points to the score. In our sample record, the R wave is clearly less than 20 times the Q-wave amplitude. Score 12 points.

(6) *Q-wave duration in leads III and $-aV_L$.* A 40-msec or larger Q wave in either lead scores 5 points. The initial R wave (¼ mm or more) in the lead aV_L is identical to the Q wave in the $-aV_L$ lead. There is no Q wave in lead III and there is no initial R wave in aV_L, so no points are scored.

(7) *T-wave amplitude in lead III.* If any portion of the T-wave measurement window is more negative than 1 mm, 5 points are scored. In figure 1, no points can be attributed to this item.

(8) *T amplitude in lead V_1.* A positive portion of the T wave (at any point 80 msec past the end of QRS) exceeding 2 mm adds 5 points to the score.

(9) *R amplitude in lead V_3.* A small or absent R wave (<3 mm) or a tall R wave (≥14 mm) contributes 5 points. In figure 1 there is a QS in lead V_3, which adds 5 points.

(10) *T amplitude in lead V_3.* Any negative T-wave segment contributes 5 points. In figure 1 there is a biphasic (positive/negative) T wave in lead V_3. However, the negative portion is less than ¼ mm with respect to the PR baseline, so no points are scored.

(11) *Q:R amplitude ratio in lead V_3.* A QS wave, or a Q wave 1/20 of the R wave, scores 9 points, as in figure 1.

(12) *S amplitude in lead V_6.* A small (<2 mm) or absent S wave in lead V_6 scores 5 points. The S amplitude in lead V_6 is clearly less than 2 mm in figure 1 and scores 5 points.

The total score from all 12 components is 38 points (48 positive and 10 negative points), and falls into CIIS severity level A.

Myocardial Infarction Injury Score

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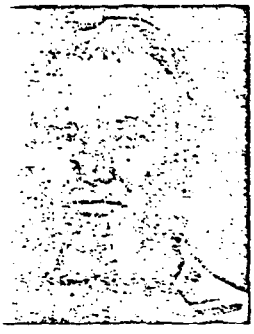

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Halifax Infirmary
Halifax, Nova Scotia

Evidence of past myocardial infarction is helpful in identifying patients at high risk for future heart attack. Current criteria are insensitive, especially if the MI is not extensive or transmural: ECG changes observed may be only nonspecific. In addition, a considerable portion of MIs may be clinically silent. The CARDIAC INFARCTION INJURY SCORE offers a new quantitative way of extracting diagnostic information that is often overlooked in ECG interpretation. A simple ECG coding form can determine the likelihood of MI or a significant "worsening" of the ECG in serial ECG comparison. This approach improves the sensitivity of MI detection while retaining adequately high specificity.

■ The poor reliability of clinical criteria for myocardial infarction (MI) is due to several conditions (Table 1). The electrocardiogram is a fairly complex multidimensional time function of electric potential differences. This poses conceptual problems, as for example in the selection of an optimal set of ECG features for differential diagnosis.

Most physicians feel more comfortable dealing with univariate or bivariate distributions of ECG measurements from contrasting MI and non-MI populations. This, perhaps, is the primary reason why many MI criteria are based on thresholds set for univariate distributions such as the Q-wave duration in lead III or aVF.

Unfortunately there is nearly always a substantial degree of overlap when univariate features are used for ECG classification. There are too many false negatives or false positives, or both, depending on threshold selection.

Despite recent advances in statistical and computer methods, the selection of optimal features for ECG classification remains a complicated statistical problem. The ostensibly trivial task of optimal threshold selection when several ECG features or variables are used simultaneously in an ECG classifier can also present difficulties.

When ECG classification is based on a single "yes or no" decision (or a few sequential steps), one relatively small measurement error may lead to misclassification. Similarly, a small degree of biologic or technical varia-

tion, such as electrode placement errors, can radically influence the ECG classification.

FAST TAKE

Misclassification: When ECG classification is based on a few sequential steps or there is some degree of biologic or technical variation (e.g., error in electrode placement), misclassification can easily result. Infarctions in areas that do not involve the initial sequence of ventricular excitation are often missed because MI has traditionally been diagnosed by looking for Q waves.

Finally, because MI has traditionally been diagnosed by looking for Q waves, infarctions in areas that do not involve the initial sequence of ventricular excitation tend to be missed. The Cardiac Infarction Injury Score (CIIS) offers a new way of quantifying "non-specific" diagnostic information that is often overlooked in clinical ECG interpretation.

The CIIS ECG Classifier

The CIIS classifier was developed from a data file containing the ECGs of 387 MI patients and 320 persons without infarction. Selection criteria for the MI group,

Continued on page 179

Table 1
Problems with Current MI Criteria

Mainly insensitive univariate features
Large overlap of MI, non-MI populations
Suboptimal thresholds
Overemphasis on Q waves
Vulnerable to biological and technical variation.

Table 2
Valuable ECG Features often Overlooked in Diagnostic Interpretation

Absent Q wave in aVL
Initial R-wave duration in aVL
Small S in aVR (or small R in inverted aVR)
Negative T in III
Positive T in V_1
Tall R in V_2
Small S in V_5 and V_6

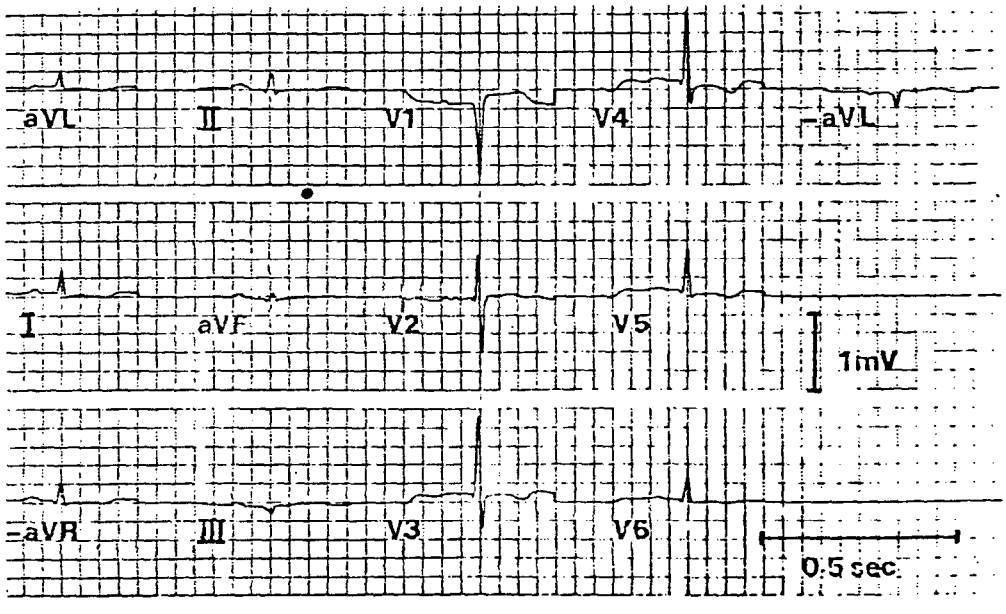

Fig. 1. A sample ECG for practice coding using the CIIS coding form in Table 3. The amplitude scale is expanded (20 mm = 1 mV) and the speed is 50 mm/sec. *Note:* -aVR is the inverted aVR and -aVL is the inverted aVL lead.

Table 3
CIIS Coding Form

Component	Feature		Limits/Score 0	.01	.02	.03	.04	.05	Units	Score
1	Q aVL	Score	☐ 5	☐ 1	☐ 3	☐ 9	☐ 10	☐ 12	Sec	____
2a	T Pos aVL	Score				≤ .5 ☐ 3		≥ 3 ☐ 3	mm	____
2b	T Neg aVL	Score	.5 ☐ 1	1 ☐ 2	2 ☐ 5	3 ☐ 7	4 ☐ 10	5 ☐ 12	mm	____
3	R – aVR	Score	0 ☐ 0	2 ☐ -2	4 ☐ -4	6 ☐ -6	8 ☐ -8	10 ☐ -10	mm	____
4	T Pos – aVR	Score	0 ☐ 6	1 ☐ 3	2 ☐ 0	3 ☐ -2	4 ☐ -5	5 ☐ -7	mm	____
5	Q:R II, aVF	Score				<⅛ ☐ 0		≥ ⅛ ☐ 12		____
6	Q III. – aVL	Score				<.04 ☐ 0		≥ .04 ☐ 5	sec	____
7	T Neg III	Score				<1 ☐ 0		≥ 1 ☐ 7	mm	____
8	T Pos V_1	Score				≤ 2 ☐ 0		>2 ☐ 4	mm	____
9	R V_2	Score				<3 ☐ 5		≥ 14 ☐ 5	mm	____
10	T Neg V_2	Score				<¼ ☐ 0		≥ ¼ ☐ 5	mm	____
11	Q:R V_5	Score				≤ 1/20 ☐ 0		>1/20 ☐ 9		____
12	S V_5	Score				≥ 2 ☐ 0		<2 ☐ 5	mm	____
									Total Score	____

Definitions and CIIS coding rules

1. All amplitude measurements are made with respect to PR baseline at the beginning of QRS.
2. Q wave: Initial QRS deflection exceeding ¼ mm if it is negative.
3. R wave: Largest positive deflection within QRS exceeding ¼ mm. If no R wave meets this definition, QRS is labeled QS wave.
4. For CIIS coding, QS qualifies for a Q wave.
5. S wave: Largest negative deflection within QRS, following a positive deflection exceeding ¼ mm.
6. T Pos: Largest positive ST-T amplitude within a window 80 msec past the end of QRS to the end of T.

Severity Levels of the MI Score

The MI score is classified at three levels of the likelihood of an MI:

1. Level A: MI score 20 or more, indicates probable injury, with an estimated specificity of 98 per cent (i.e., 2 per cent false positives expected).
2. Level B: MI score 15 or more but less than 20, indicates possible injury, with an estimated specificity of 96 per cent.
3. Level C: MI score 10 or more but less than 15, indicates a borderline abnormality, with 90 per cent specificity.

The CIIS Scoring Procedure

The ECG in Fig. 1 is used here to illustrate the CIIS coding form shown in Table 3. Note that the amplitude scale has been expanded two-fold (i.e., 20 mm = 1 mV). The paper speed is 50 mm/sec. One averaged complex is shown for each lead. The leads have been grouped for convenience to follow the sequence of the 12-step procedure. This sequence also follows the logical order of the orientation of lead vectors in the frontal plane from aVL through III. Note that the inverted lead aVR (– aVR) falls between leads I and II.

Step 1. Q in aVL is absent. Score 5 points.

Step 2a. T Pos aVL: The largest positive STT amplitude is less than 0.5 standardized mm. Score 3 points.

Step 2b. T Neg aVL: The largest negative STT amplitude is 0.5 standardized mm. Score 1 point.

Step 3. R – aVR: R in inverted aVR is 2.5 standardized mm. This is closer to 2 than 4 mm, and the score is –2. *Subtract* 2 points from the total score.

Step 4. T Pos – aVR: The largest positive amplitude in inverted aVR is 0. Score 6 points.

Step 5. Q:R II, aVF: Largest Q:R ratio in II and aVF. There is a Q wave in both leads. Although exact amplitude measurement may be difficult to read in Fig. 1, the Q:R amplitude ratio measured from the original ECG is ⅗. This exceeds the limit ⅕. Score 12 points.

Step 6. QIII, – aVL: There is a QS wave in III and inverted aVL, both exceeding 40 msec. Score 5 points.

Step 7. T Neg III: There is no negative STT deflection in III exceeding 1 mm. Score 0.

Step 8. T Pos V_1: There is a positive T wave in V_1. However, the largest positive STT amplitude is 1.5 standardized mm, which is less than the 2 mm limit given. Score 0.

Step 9. RV_2: R amplitude in V_2 about 5 standardized mm, which is more than 3 and less than 14 mm, the abnormal limits given. Score 0.

Step 10. T Neg V_2: There is no negative STT amplitude in V_2 exceeding ¼ mm. Score 0.

Step 11. Q:R V_3: The Q wave in V_3 is over 0.5 mm and the R wave is 10 mm. Q:R ratio exceeds $\frac{1}{20}$. Score 9 points.

Step 12. SV_5: S-wave amplitude in V_5 is 1 standardized mm. This is less than the 2 mm limit given. Score 5 points.

The total score is 44 points, which is far in excess of the limit 20, or CIIS level A, probable injury. ECG changes are relatively minor, with the exception of slightly negative T waves in the left-sided leads and QS in V_1 with 1 mm ST-segment elevation. There are no diagnostic Q waves.

The patient died from a massive acute recurrent infarction 3 weeks after the ECG was taken. This was confirmed on autopsy, which also showed a recent nontransmural septal infarction and a small right ventricular aneurysm in the anterior wall near the border of the left ventricle. This old septal infarction probably is associated with the typical enzyme changes that peaked 2 days after the ECG in Fig. 1 was recorded.

7. T Neg: Largest negative ST-T amplitude within a within a window 80 msec past the end of QRS to the end of T.
8. -aVR lead: Inverted unipolar aVR lead.
9. R -aVR: R amplitude in inverted aVR. This is equivalent to a Q, S, or QS amplitude in ordinary aVR, whichever is largest.
10. T pos -aVR: T pos amplitude in inverted aVR. This is equal to T neg amplitude in ordinary aVR.
11. -aVL lead: Inverted unipolar aVL.
12. Q -aVL: Q duration in inverted aVL. This is equivalent to initial R-wave duration in ordinary aVL.
13. Absolute values of negative waves are used for the limits of criteria in Table 3.

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seen at the Halifax Infirmary, were based on non-ECG clinical evidence in the acute phase, including a peak CPK enzyme level more than 85 per cent above the upper limit of normal. The non-MI group consisted of 145 subjects with sustained hypertension, but no clinical evidence of MI, and 175 healthy subjects with normal blood pressure.

The procedures used involved optimization of thresholds for each variable, and an extensive search for the best combination of variables for a linear discriminant type ECG classifier. Whether any given variable was more suitable for MI classification as a continuous variable (e.g., T amplitude) or a discrete variable with one or two thresholds (e.g., R amplitude in $V_2 < 3$ mm or > 14 mm) was also determined. The specific statistical methods used are described in detail elsewhere (Circulation *64*:249, 1981).

"Hidden" Diagnostic Information

In the course of CIIS development, it has become obvious that an abundance of usually ignored diagnostic information is contained in the 12-lead ECG (Table 2). Lead aVR, for instance, contributed significantly to MI detection. Although this may seem implausible at first, if the inverted aVR is seen as a lead between leads I and II in the frontal plane, it can be readily understood that a reduced R amplitude and a flat T wave in that lead is indeed relevant in separating MIs from non-MIs.

FAST TAKE

The 12-Lead ECG: An abundance of diagnostic information is contained in the 12-lead ECG. MI detection is significantly enhanced by lead aVR: a reduced R amplitude and a flat T wave in this lead can help discriminate between MIs and non-MIs.

A Q wave in an inverted aVL lead also contributes information, as do other inferiorly oriented leads. This information can be extracted from an ordinary aVL lead by measuring the *initial* R wave *duration*.

MI Scoring Procedure

Cardiac infarction scoring requires 12 observations on 9 leads (Table 3). At each step, the observer verifies whether a given feature is present and then checks to see if a given threshold (or thresholds) is exceeded; if so, the appropriate box is marked on the coding sheet.

Three of the items on the criteria list in Table 3, components 2b, 3, and 4, use measurements on a continuous rather than a discretized scale, and the scoring points depend on the measured value. For convenience, these continuous variables were discrete at six levels, permitting enough accuracy for practical clinical application. After checking all 12 ECG features individually, the total MI score is obtained by adding up the contributions of each component.

A relatively small subset of the features is usually abnormal and may be readily identified after one becomes familiar with the features and thresholds used. It is still recommended, however, that the 12-step sequence be followed systematically to reduce the chance of human error in ECG coding and interpretation.

Table 4
Diagnostic Accuracy of the CIIS Classifier in Design and Test Sets.*

Design File		Test File	
Specificity (%)	Sensitivity (%)	Specificity (%)	Sensitivity (%)
90	97	89	94
96	94	93	92
98	88	95	85
100	71	99	71

*The cutoff points of the score were chosen to yield a specificity of 90, 98, and 100 per cent in the design file.

FAST TAKE

MI Scoring involves 12 observations on 9 leads. The presence or absence of a given feature is verified at each step and threshold measurements are checked. The MI score is made up of the sum of the individual components. The 12-step sequence should be followed systematically to avoid possible errors in ECG coding and interpretation.

CIIS Diagnostic Accuracy

One-third of the ECG data file mentioned earlier was randomly chosen to test the diagnostic accuracy of the CIIS classifier. This file was not used in designing the classifier in order to avoid overestimating its accuracy. Table 4 lists the per cent sensitivity of the CIIS in the design and test files at various levels of specificity. Performance evaluation in various subsets of the test population suggests that CIIS accuracy is good and relatively uniform regardless of the age and location of the infarct. □

ARIC COHORT
12 Lead Resting
ECG Coding Form

ID: ☐ - ☐☐☐☐☐☐ Acrostic: ☐☐☐☐

ECG Technician Code : ☐☐☐

Type of visit: 1 ☐ Baseline Visit

2 ☐ Second Visit

ECG Coder No. : ☐☐☐

Date ECG recorded at Field Center: ☐☐ Day ☐☐ Month ☐☐ Year

Date sent to Minnesota Coding Center from Halifax: ☐☐ Day ☐☐ Month ☐☐ Year

Date of coding: ☐☐ Day ☐☐ Month ☐☐ Year

Q and QS Patterns (1X)			S - T Junction and Segment Depression (4X)			T Wave Items (5X)			ST Segment Elevation (9.2)			R	A-V Conduction Defect	Ventricular Conduction Defect	Miscellaneous Items				Heart Rate (per minute)			Suppls.	Techprob	CLEAR
1L V_6	23 F	V_1 V_5	1L V_6	23 F	V_1 V_5	1L V_6	23 F	V_1 V_5	1L V_6	23 F	V_1 V_5	3 X	(6X)	(7X)	91	93	95	U				8	98	1.0

Specify: _____

Comparison Rules for Simultaneously Evaluated ECGs

Event ECG Minnesota Code Q-Code	Comparison Rule for Determining Significant Increase in ECG Pattern
1-1-1	Requires $\geq$ 50% increase in event Q/R ratio or $\geq$ 1 mm initial R-wave amplitude decrease in event ECG compared with corresponding lead(s) of baseline ECG.
1-1-2	Requires $\geq$ 50% increase in event ECG Q/R ratio or $\geq$ 1.5 mm initial R-wave amplitude decrease in event ECG compared with corresponding lead(s) of baseline ECG. New appearance of QS complex in event leads to the left of V_1 when V_1 does not show change will also be judged as significant increase.
1-1-3	Requires $\geq$ 75% increase in lead aVL Q/R ratio of event ECG or $\geq$ 1 mm initial R-wave amplitude decrease in lead aVL of event ECG compared with lead aVL of baseline ECG.
1-1-4	Requires $\geq$ 50% increase in lead III Q/R ratio of event ECG or $\geq$ 1 mm initial R-wave amplitude decrease in lead III of event ECG compared with lead III of baseline ECG.
1-1-5	Requires $\geq$ 50% increase in lead aVF Q/R ratio of event ECG or $\geq$ 1 mm initial R-wave amplitude decrease in lead aVF of event ECG compared with lead aVF of baseline ECG.
1-1-6	Requires $\geq$ 1 mm decrease in event ECG initial R-wave amplitude in the "lead to the left" compared with corresponding lead of baseline ECG.
1-1-7	Requires $\geq$ 1 mm decrease in event ECG initial R-wave compared with corresponding lead(s) of baseline ECG. If V5 is the only lead with $\geq$ 1 mm decrease in initial R in event, there is no significant increase.
1-2-1	Requires $\geq$ 50% increase in event ECG Q/R ratio or $\geq$ 1 mm initial R-wave amplitude decrease in event ECG compared with corresponding lead(s) of baseline ECG.
1-2-2	Requires $\geq$ 50% increase in event ECG Q/R ratio or $\geq$ 1 mm initial R-wave amplitude decrease in event ECG compared with corresponding lead(s) of baseline ECG.
1-2-3	Requires $\geq$ 1 mm decrease in event ECG initial R-wave amplitude compared with corresponding lead(s) of baseline ECG.

Event ECG
Minnesota Code

Q-Code	Comparison Rule for Determining Significant Increase in ECG Pattern
1-2-4	Requires ≥ 50% increase in lead III Q/R ratio of event ECG or ≥ 1 mm initial R-wave amplitude decrease in lead III of event ECG compared with lead III of baseline ECG.
1-2-5	Requires ≥ 50% increase in lead aVF Q/R ratio of event ECG or ≥ 1 mm initial R-wave amplitude decrease in lead aVF of event ECG compared with lead aVF of baseline ECG.
1-2-6 in III	Requires ≥ 75% increase in lead III Q/R ratio of event ECG plus the appearance of a codable and NEW Q-wave in aVF OR ≥ 1 mm initial R-wave amplitude decrease in lead III of event ECG plus the appearance of a codable and NEW Q-wave in aVF compared with leads III and aVF of baseline ECG.
1-2-6 in aVF	Requires ≥ 75% increase in lead aVF Q/R ratio of event ECG or ≥ 1 mm initial R-wave amplitude decrease in lead aVF of event ECG compared with lead aVF of baseline ECG.
1-2-7	Requires ≥ 1 mm decrease in event ECG initial R-wave amplitude compared with corresponding lead(s) of baseline ECG.
1-2-8	Requires ≥ 1 mm decrease in event ECG initial R-wave amplitude in the "lead to the left" compared with corresponding lead of baseline ECG.
1-3-1	Requires ≥ 50% increase in event ECG Q/R ratio or ≥ 1 mm initial R-wave amplitude decrease in event ECG compared with corresponding lead(s) of baseline ECG.
1-3-2	Requires ≥ 1 mm decrease in event ECG initial R-wave amplitude compared with corresponding lead(s) of baseline ECG.
1-3-3	Requires ≥ 50% increase in lead aVL Q/R ratio of event ECG or ≥ 1 mm initial R-wave amplitude decrease in lead aVL of event ECG compared with lead aVL of baseline ECG.
1-3-4	Requires ≥ 50% increase in lead III Q/R ratio of event ECG or ≥ 1 mm initial R-wave amplitude decrease in lead III of event ECG compared with lead III of baseline ECG.
1-3-5	Requires ≥ 50% increase in lead aVF Q/R ratio of event ECG or ≥ 1 mm initial R-wave amplitude decrease in lead aVF of event ECG compared with lead aVF of baseline ECG.
1-3-6	Requires ≥ 1 mm decrease in initial R-wave amplitude in both III and aVF of event ECG compared with leads III and aVF of baseline ECG.

ST Depression Code - Increase

4-1 Requires baseline record have no 4-1 or 4-2, and 4-1 appears in event ECG, OR there must be 100% AND $\geq$ 1 mm change in event ECG ST segment depression compared with corresponding lead(s) of baseline ECG.

4-2 Requires baseline record have no 4-1 or 4-2 or 4-3 codes, and 4-2 appears in event ECG, OR there must be 50% AND $\geq$ 1 mm change in event ECG ST segment depression compared with corresponding lead(s) of baseline ECG.

T-wave
Inversion Code-Increase

5-1 Requires baseline record have no 5-1 or 5-2 codes, and 5-1 appears in event ECG, OR there must be a 100% AND 1 mm change in T-wave inversion compared with corresponding lead(s) of baseline ECG.

5-2 Requires baseline record have no 5-1 or 5-2 or 5-3 code, and 5-2 appears in event ECG, OR there must be a 50% AND 1 mm change in T-wave inversion compared with corresponding lead(s) of baseline ECG.

ST Elevation
Code-Increase

9-2 Requires baseline record have no 9-2 code, and 9-2 appears in event ECG, OR there must be 100% and 1 mm change in event ECG ST segment elevation compared with corresponding lead(s) of baseline ECG.

Left Bundle
Branch Block
Code-Increase

7-1-1 Requires baseline record have no 7-1-1 and new 7-1-1 code appears in event ECG with a QRS duration increased by 0.02 sec. in event ECG compared with baseline ECG.

*Majority rule applies for all codes.

(Final pattern in baseline based on majority vs. final pattern in event based on majority).

ST Depression Code - Decrease

4-1 Requires event record have no 4-1 or 4-2, and 4-1 appears in baseline ECG, OR there must be 50% AND $\geq$ 1 mm change in event ECG ST segment depression compared with corresponding lead(s) of event ECG.

4-2 Requires event record have no 4-1 or 4-2 or 4-3 codes, and 4-2 appears in baseline ECG, OR there must be 50% AND $\geq$ 1 mm change in baseline ECG ST segment depression compared with corresponding lead(s) of event ECG.

T-wave
Inversion Code-Decrease

5-1 Requires event record have no 5-1 or 5-2 codes, and 5-1 appears in baseline ECG, OR there must be a 50% AND 1 mm change in baseline T-wave inversion compared with corresponding lead(s) of event ECG.

5-2 Requires event record have no 5-1 or 5-2 or 5-3 code, and 5-2 appears in baseline ECG, OR there must be a 50% AND 1 mm change in baseline T-wave inversion compared with corresponding lead(s) of event ECG.

ST Elevation
Code-Decrease

9-2 Requires event record have no 9-2 code, and 9-2 appears in baseline ECG, OR there must be 50% and 1 mm change in baseline ECG ST segment elevation compared with corresponding lead(s) of event ECG.

Left Bundle
Branch Block
Code-Decrease

7-1-1 Requires event record have no 7-1-1 and new 7-1-1 code appears in baseline ECG with a QRS duration increased by 0.02 sec. in baseline ECG compared with event ECG.

*Majority rule applies for all codes.

(Final pattern in event based on majority vs. final pattern in baseline based on majority).

ARIC - Minnesota Coding and Serial Change Form
Field Center Visit ECGs

DAY MONTH YEAR

Date of Coding ___ ___ ___

Coder Number ___ ___ ___

ID: _____

	I,aVL V6	1-X-X II,III aVF	V1-V5	I,aVL V6	4-X-X II,III aVF	V1-V5	5-X I,L 6	5-X 2,3 F	5-X V1-V5	9-2 I,L 6	9-2 2,3 F	9-2 V1-V5	7-1-1	9-8-X	Suppression Code
Reference ECG First Visit date of ECG (dd / mm / yy) ___/___/___															
Comparison ECG Second Visit ___/___/___															
REFERENCE VS THIS ECG															
1=Significant INCREASE	1														
2=Significant DECREASE	Do not look for Decrease between ARIC Field Center Visits														
3=No Increase	3														
4=Technical Problems	4														

Appendix N

ARIC COHORT
Two Minute Rhythm Strip
ECG Coding Form

ID: ☐ - ☐☐☐☐☐☐ Acrostic: ☐☐☐☐

ECG Technician Code : ☐☐☐

Type of visit: 1 ☐ Baseline Visit

ECG Coder No. : ☐☐☐

2 ☐ Second Visit

Date ECG recorded at Field Center: ☐☐ Day ☐☐ Month ☐☐ Year

Date sent to Minn. Coding Center from Field Center: ☐☐ Day ☐☐ Month ☐☐ Year

Date of coding: ☐☐ Day ☐☐ Month ☐☐ Year

Arrhythmias (8X)						Ectopic Codes					QT Duration (msec)	Coupling Interval (m. sec.)	R-R (m.m.)	Heart Rate (per minute)	TechProb 98	CLEAR 1.0
1X	2X	3X	4X	5X	6X	SVPB	VPB	RN BG	M F	T-R						

Specify: _____

ARIC - Minnesota Coding and Serial Change Form

Hospital ECGs - Mark one: Cohort ___
Surveillance Quality Control ___

DAY MONTH YEAR

Date of Coding: ___ ___ ___

Coder Number: ___ ___ ___

ID: ______________________

Reference ECG First of Set date of ECG (dd / mm / yy) ___/___/___	1-X-X I,aVL V6	1-X-X II,III aVF	1-X-X V1-V5	4-X-X I,aVL V6	4-X-X II,III aVF	4-X-X V1-V5	5-X I,L 6	5-X 2,3 F	5-X V1-V5	9-2 I,L 6	9-2 2,3 F	9-2 V1-V5	7-1-1	9-8-X	Suppression Code

Comparison ECG Next of Set ___/___/___	1-X-X I,aVL V6	1-X-X II,III aVF	1-X-X V1-V5	4-X-X I,aVL V6	4-X-X II,III aVF	4-X-X V1-V5	5-X I,L 6	5-X 2,3 F	5-X V1-V5	9-2 I,L 6	9-2 2,3 F	9-2 V1-V5	7-1-1	9-8-X	Suppression Code
REFERENCE VS THIS ECG 1=Significant INCREASE 2=Significant DECREASE 3=No Change * 4=Technical Problems	1 / No Decrease for Q-codes / 3 / 4														

Comparison ECG Next of Set ___/___/___	1-X-X I,aVL V6	1-X-X II,III aVF	1-X-X V1-V5	4-X-X I,aVL V6	4-X-X II,III aVF	4-X-X V1-V5	5-X I,L 6	5-X 2,3 F	5-X V1-V5	9-2 I,L 6	9-2 2,3 F	9-2 V1-V5	7-1-1	9-8-X	Suppression Code
REFERENCE VS THIS ECG 1=Significant INCREASE 2=Significant DECREASE 3=No Change * 4=Technical Problems	1 / No Decrease for Q-codes / 3 / 4														

Comparison ECG Next of Set ___/___/___	1-X-X I,aVL V6	1-X-X II,III aVF	1-X-X V1-V5	4-X-X I,aVL V6	4-X-X II,III aVF	4-X-X V1-V5	5-X I,L 6	5-X 2,3 F	5-X V1-V5	9-2 I,L 6	9-2 2,3 F	9-2 V1-V5	7-1-1	9-8-X	Suppression Code
REFERENCE VS THIS ECG 1=Significant INCREASE 2=Significant DECREASE 3=No Change * 4=Technical Problems	1 / No Decrease for Q-codes / 3 / 4														

Comparison ECG Next of Set ___/___/___	1-X-X I,aVL V6	1-X-X II,III aVF	1-X-X V1-V5	4-X-X I,aVL V6	4-X-X II,III aVF	4-X-X V1-V5	5-X I,L 6	5-X 2,3 F	5-X V1-V5	9-2 I,L 6	9-2 2,3 F	9-2 V1-V5	7-1-1	9-8-X	Suppression Code
REFERENCE VS THIS ECG 1=Significant INCREASE 2=Significant DECREASE 3=No Change * 4=Technical Problems	1 / No Decrease for Q-codes / 3 / 4														

* For Q-codes, No Change implies No Increase.

P R O T O T Y P E

ARIC Hospital Surveillance ECG Classification ID: __-__ __ __ __ __ __

First ECG ☐. Last ECG ☐. Last ECG of day 3 ☐. Date of ECG:____/____/____

A. Check one: 1. ECG not classified because of a Suppression Pattern ☐
2. ECG not classified because Uncodable ☐
3. ECG classified below ☐.

B. Check one: Does ECG have 7-1-1 or 7-2-1? 1. NO ☐, 2. YES ☐ _____ (specify, see note below)

C. Check one: (Look for 1. first, then 2.)

	LEAD	CHARACTERISTICS	ALSO MUST HAVE
1. ☐	I	QS Pattern	*--
	I or V6	Q =› 0.03 sec	--
	I or V6	Q =› 0.02 sec	Q/R ratio =› 1/3 in same beats
	AVL	Q =› 0.04 sec	R amp. =› 3mm in same beats
2. ☐	I or V6	Q =› 0.02 sec	Q/R ratio =› 1/5 in same beats
	AVL	Q =› 0.03 sec	R amp. =› 3mm in same beats
3. ☐	I AND AVL AND V6 -- NONE OF THE ABOVE		

D. Check one: (Look for 1. first, then 2.)

1. ☐	II	QS Pattern	*--
	II	Q =› 0.03 sec	--
	II	Q =› 0.02 sec	Q/R ratio =› 1/3 in same beats
	lead III	Q =› 0.04 sec	Q =› 1mm deep in majority in AVF
	AVF	Q =› 0.04 sec	--
2. ☐	II	Q =› 0.02 sec	Q/R ratio =› 1/5 in same beats
	lead III	Q =› 0.03 sec	Q =› 1mm deep in majority in AVF
	lead III	QS Pattern	*QS Pattern in AVF
	AVF	Q =› 0.03 sec	--
3. ☐	II AND III AND AVF -- NONE OF THE ABOVE		

E. Check one: (Look for 1. first, then 2.)

1. ☐	V1	Q =› 0.04 sec	--
	V1	QS Pattern	QS Pattern in V2 AND V3 AND V4
	V1	QS Pattern	*QS Pattern in V2 AND V3
	any of V2 - V5	Q =› 0.03 sec	--
	any of V2 - V5	Q =› 0.02 sec	Q/R ratio =› 1/3 in same beats
	V1	Initial R in maj.	QS Pattern in V2
	V2	any Initial R	QS Pattern in V3
	V3	any Initial R	QS Pattern in V4
	V4	any Initial R	QS Pattern in V5
	V5	any Initial R	QS Pattern in V6
2. ☐	V1	QS Pattern	*QS Pattern in V2
	any of V2 - V5	Q =› 0.02 sec	Q/R ratio =› 1/5 in same beats
	V1	Initial R › 2mm	**Initial R ‹= 2mm in V2 (Init. R's
	V2	Initial R › 2mm	**Initial R ‹= 2mm in V3 in ALL
	V3	Initial R › 2mm	**Initial R ‹= 2mm in V4 beats of
	V4	Initial R › 2mm	**Initial R ‹= 2mm in V5 BOTH
	V5	Initial R › 2mm	**Initial R ‹= 2mm in V6 leads.)
3. ☐	V1 AND V2 AND V3 AND V4 AND V5 -- NONE OF THE ABOVE		

* Do not look for this if ECG has 7-1-1 (Left Bundle Branch Block)
** Do not look for this if ECG has 7-1-1 OR 7-2-1 (Right BBB)

ECG Technician Procedure Review Checklist Form

This form is required for ECG technician certification, recertification and quality control. It is to be completed by the ECG technician training supervisor by observing the ECG technician taking an ECG recording. The ECG recording should be done on a non-study individual. Quality control observations should occur every three months.

The ECG training supervisor should not make any comments during the recording. The steps outlined below should be done in the order indicated. Any departure from this sequence should be noted in the comments section of the form.

I. Identifying Information

1. Field Center: _____

2. ECG Technician: _____ Tech. No. _____

3. ECG Supervisor: _____ Tech. No. _____

Technician Procedure Review

	Yes	No	Comments
1. Subject asked to disrobe to the waist.	( )	( )	_____
2. Subject instructed to lie on the recording bed with arms relaxed at the sides.	( )	( )	_____
3. Electrode areas wiped with alcohol.	( )	( )	_____
4. V2 position correctly marked.	( )	( )	_____
5. V1 position correctly marked.	( )	( )	_____
6. E Point position correctly marked.	( )	( )	_____
7. V6 position correctly marked using chest square.	( )	( )	_____
8. V4 position correctly marked using tape measure.	( )	( )	_____
9. V3 position correctly marked using flexible ruler.	( )	( )	_____
10. V5 position correctly marked using flexible ruler.	( )	( )	_____
11. Limb leads correctly marked.	( )	( )	_____
12. Electrode sites sanded with three light strokes of the paper.	( )	( )	_____
13. Electrodes placed with the tabs in the correct positions.	( )	( )	_____
14. Electrodes massaged in a small circular motion.	( )	( )	_____
15. Appropriate leadwire clipped to each electrode.	( )	( )	_____
16. Participant information entered into the MAC PC according to Appendix I.	( )	( )	_____
17. Electrodes and leadwires checked.	( )	( )	_____
18. Subject asked to relax and keep still.	( )	( )	_____
19. Electrodes on skin 2-5 minutes before taking ECG.	( )	( )	_____

	Yes	No	Comments
20. MAC PC display watched for error messages.	( )	( )	_____
21. If error message(s): Electrode contacts and leadwires checked, display observed again.	( )	( )	_____
22. If display counts past 75: Skin preparation and electrode placement repeated with new electrodes.	( )	( )	_____
23. ECG tracing removed from the MAC PC.	( )	( )	_____
24. ECG tracing examined for baseline drift, noise, 60-cycle interference and muscle tremor.	( )	( )	_____
25. When technically inadequate, ECG re-recorded until an acceptable recording is achieved.	( )	( )	_____
26. Rhythm strip recorded immediately after 12-lead ECG.	( )	( )	_____
27. Stop watch or watch with second hand used to time two minutes.	( )	( )	_____
28. Starting time established for two minute strip when the baseline is stable.	( )	( )	_____
29. Electrodes removed and these areas wiped.	( )	( )	_____
30. The strip folded accordion style.	( )	( )	_____

Review and Administrative Information

31. Overall assessment of performance:

Excellent .....( )
Good .....( )
Fair .....( )
Poor .....( )

32. Reasons for assessment listed above:

_____

_____

_____

Review and Administrative Information, Cont.

33. Results reviewed by the ECG technician and supervisor

    a. Signature of ECG technician supervisor _____

    b. Signature of ECG technician _____

34. Today's date.....__ __ / __ __ / __ __
day mo. year

Please forward this form and other related materials to the Coordinating Center.

Editing Patient Name and ID

1) Place the data diskette, write-protect off, in the MAC 12 and power it on.
2) Select the system menu with Shift/F1.
3) Press F2 to select DISK FUNCTIONS.
4) Press F2 to select EDIT FUNCTIONS.
5) Press F2 to select PATIENT DATA
6) Press [RTN] to start diskette read.
7) Press F2 [RTN] to SELECT BY FILE CONTENTS.
8) Press F1 [RTN] to Set Up Selection Parameters.
9) Press [RTN], do not select by Patient ID.
10) Press F1 [RTN] to select by Site.
11) Enter Site number (Field Center number). Press [RTN].
12) Press [RTN] when asked for Location, Cart and Confirmed.
13) The ID of the first quality control ECG for that Field Center will appear.
14) Press F3 to select all ECGs from that Field Center.
15) The first QC ID will appear again.
16) Press [RTN] to start editing.
17) When the Last Name appears, edit it as required. Press [RTN]
18) When First Name appears, replace digit portion of ID with new ID number. Press [RTN].
19) When ID appears, replace ID with new ID number.
20) Press F1 (OK).
21) Press F2, do not print the ECG.
22) The new data will be written on the diskette.
23) Edit the rest of the ECGs in the same way.
24) REMOVE THE DISKETTE AND SET WRITE-PROTECTION "ON". ECGs will be deleted if transmitted with write-protection off.

Quality Control
Retransmission Documentation

Date of Retransmission (dd/mm/yy): __ __/__ __/__ __

Original Name	ID	Retransmission Name	ID
_____	__-_____	_____	__-_____
_____	__-_____	_____	__-_____
_____	__-_____	_____	__-_____
_____	__-_____	_____	__-_____
_____	__-_____	_____	__-_____
_____	__-_____	_____	__-_____
_____	__-_____	_____	__-_____
_____	__-_____	_____	__-_____

ARIC

ECG CERTIFICATION

(To be filled in by Field Center)

ECG Technician Name: _____ Number: [ ][ ]

Field Center: _____

Date Certification Tracings Taken: _____

Date Tracings Sent to Coordinating Center: _____

Instructions:

Obtain three 12-lead resting ECGs and two-minute rhythm strips as specified in the ARIC ECG Procedures. Write the Technician name on the ECG, the Technician number must be printed by the MAC PC next to the word Room.

Send the ECGs, rhythm strips and one copy of this form to the ARIC Coordinating Center. Tracings will be forwarded to the ECG Coding Center for certification. Notification of the technician's certification status is made by the Coordinating Center upon receipt of this completed form from the ECG Coding Center.

(To be filled in be Coordinating Center)

Date Tracings and Form Received by Coordinating Center: _____

Date Tracings sent to ECG Coding Center: _____

(To be filled in by ECG Coding Center)

Date Tracings Received: _____

Comments:

Certified Yes _____ _____

Signature of Certifying Agent

No _____ _____

Date

Date Sent to Coordinating Center: _____

Procedures for MAC PC Calibration Check

ECG Coding Center Procedures

The Calibration Coordinator manages the sending and receiving of the Marquette ECG simulator. Each ARIC Field Center receives the ARIC simulator once every three months. The simulator is sent via Certified Mail, return receipt requested.

Upon receiving a calibration ECG from a Field Center, the Calibration Coordinator measures the waves required in the Calibration Check form (Appendix V2). If there is wave distortion compared to the ECG taken at the ECG Coding Center on February 20, 1987, the Calibration Coordinator notifies the Coding Lab Supervisor. The Coding Lab Supervisor contacts the Field Center about appropriate action.

The Calibration Coordinator enters the data and graphs comparisons of wave height at the end of every calandar quarter. These results are sent to the Coordinating Center.

ARIC Field Center Procedures

Within two days of receiving the sumulator, take one noise-free 12-lead ECG following the instructions below.

Instructions for taking a 12-lead ECG using the Marquette ECG Simulator:

1. Make sure the ECG Simulator switch is above "off" unless actually in use. Leaving it "on" drains the battery.
2. Check the battery: push the switch to "test". The yellow light should go on. If it doesn't, unscrew the back of the simulator and replace the old battery with the new battery included in the mailing.
3. Remove the adaptor wires (clips) from the lead wire plugs.
4. Plug each lead wire into the simulator in its proper hole.
5. Turn the Heart Rate knob all the way to the left so the white line is at the number 68 (as in 'beats per minute'). Don't try to line up the line with the dot, just turn it all the way left.
6. Press F1 (PatInfo).
7. For Last Name: CALIBRATION TEST.
8. For First Name: Site Number
   (MN = 5, NC = 6, MD = 7, MS = 8)
9. For ID number put Technician ID.
10. Press Return.
11. Press the STOP symbol when it asks for Reffered by:
12. Now the screen is back to the Main Menu.
13. Turn on the ECG Simulator or else you will get a flat line!
14. Press the 12-lead Record key. Machine will take, print and store an ECG.
15. Turn off the ECG Simulator.

. ARIC Field Center Procedures (continued)

If you have trouble getting a noise-free ECG, try twisting the plugs in their holes and take another ECG. Otherwise, there might be something wrong with your Acquisition Module (the white box with all the lead wires coming out of it).

a. Phone the Coding Center and we will send you our Acquisition Module.
b. Try taking another ECG using out module.
c. If the tracing is better, contact Marquette about replacing your module.
d. If you are still getting lots of noise, take the appropriate steps to have your machine serviced..

Do not take a 2-minute rhythm strip using the simulator.

Transmit the Calibration ECG with your next batch to Halifax. Delete it upon confirmation.

Return the simulator and ONLY ONE 12-lead ECG (the best one if you took more than one) immediately via Certified Mail, return receipt requested to:

Mr. Lowell Hedquist
ECG Coding Center
Stadium Gate 27
611 Beacon St. S.E.
Minneapolis, MN 55455

(Please pack the simulator very carefully!)

Marquette ECG Simulator Measurements

Study: _____

Location of Clinic: _____ Date of ECG: _____

Type of Electrocardiograph _____

Simulator used: ARIC TOMHS

PAPER SPEED:

Overall: Measure from the peak of the R of the first complete R-wave in Lead I to the peak of the 6th R-wave, (5 intervals).

_____mm / 5 intervals = $\frac{\text{\_\_\_\_\_}}{\text{mm / interval}}$ = $\frac{\text{\_\_\_\_\_}}{\text{overall HR}}$

Short Term: Measure interval between first and second complete R-waves.

$\frac{\text{\_\_\_\_\_mm}}{\text{1st interval}}$ = $\frac{\text{\_\_\_\_\_}}{\text{Short Term HR}}$

PR Duration: Measure the PR duration of 3 beats in Lead II to the nearest 0.25 mm.

_____ + _____ + _____ / 3 = _____ average PR duration

VOLTAGE CALIBRATION:

Measure the last 3 complete waves of the lead in question. If there are only 2 complete waves then divide by 2, instead of 3, to get the average. The beats themselves do not have to be complete.

R-wave in I: _____ + _____ + _____ / 3 = _____

R-wave in II: _____ + _____ + _____ / 3 = _____

R-wave in III: _____ + _____ + _____ / 3 = _____

Calibration: _____ + _____ + _____ / 3 = _____

T-wave in II: _____ + _____ + _____ / 3 = _____

S-wave in V1: _____ + _____ + _____ / 3 = _____

FREQUENCY RESPONSE:

Compare closely with the ECG taken by the same simulator on the Floater MAC PC on Feb. 20, 1987.
Note especially ST segment distortion.

Satisfactory? YES NO

If NO show to Dr. Prineas or Dr. Crow.

Comment: _____

_____

Definitions of Electrocardiographic Criteria

The ECG series is assigned the highest category for which criteria are met, i.e., Evolving Diagnostic ECG patterns are greater than Diagnostic ECG patterns are greater than Evolving ST-T patterns are greater than Equivocal ECG patterns are greater than Other are greater than Uncodable.

Evolving ECG Patterns (Evolving Diagnostic and Evolving ST-T):

A. Two or more recordings are needed for these classifications.
B. Changes must occur within lead groups i.e., lateral (I,aVL,V6), inferior (II,III,aVF), or anterior (V1-V5).
C. Changes must be confirmed for <u>all</u> codes by Serial ECG comparison.
Example:

	1-3-4	4-0	5-0	9-0	
reference ECG:	1-2-4	4-0	5-2	9-0	
follow-up ECG:					
Serial ECG Comparison:					Pattern:
	Inc.	--	Inc.	--	ED3 (Evolving Diagnostic)
	No Inc.	--	Inc.	--	EV3 (Evolving ST-T)
	Inc.	--	No Inc.	--	D1 (Diagnostic ECG)
	No Inc.	--	No Inc.	--	D1 (Diagnostic ECG)

To be considered Evolving Diagnostic (pattern ED3) <u>both</u> the 1-2-4 and the 5-2 must be determined to be Significant Increase by Serial Change rules. If the 1-2-4 change is not Significant Increase and the 5-2 change is Significant Increase, then the change would fit Evolving ST-T (pattern EV3). If the 5-2 change is not Significant Increase, then the pattern would be Diagnostic ECG (pattern D1) because of the 1-2-4, regardless of whether or not the 1-2-4 change is Significant Increase. The complexity of this algorithm precludes determination by Minnesota Coders. Determination is made by computer algorithm.

D. The reference ECG for Cohort Field Center Visits is the ECG taken during the first visit. The reference ECG for Cohort Hospital ECGs or Surveillance Hospital ECGs is the earliest ECG of that hospitalization.
E. Serial ECG Significant Decrease is determined only for cohort hospital ECGs and only for 4-, 5- and 9-2 codes.

<u>Evolving Diagnostic ECG</u>:

ED1. No Q-code in reference ECG followed by a record with a Diagnostic Q-code (Minn. code 1-1-1 through 1-2-5 plus 1-2-7) OR any code 1-3-x in reference ECG followed by a record with any code 1-1-x.

ED2. An Equivocal Q-code (Minn. code 1-2-8 or any 1-3 code) and no major ST-segment depression in reference ECG followed by a record with a Diagnostic Q-code PLUS a major ST-segment depression (Minn. code 4-1-x or 4-2).

ED3. An Equivocal Q-code and no major T-wave inversion in reference ECG followed by a record with a Diagnostic Q-code PLUS a major T-wave inversion (Minn. code 5-1 or 5-2).

ED4. An Equivocal Q-code and no ST-segment elevation in reference ECG followed by a record with a Diagnostic Q-code PLUS an ST segment elevation (Minn. code 9-2).

ED5. No Q-code and neither 4-1-x nor 4-2 in reference ECG followed by a record with an Equivocal Q-code PLUS 4-1-x or 4-2.

ED6. No Q-code and neither 5-1 nor 5-2 in reference ECG followed by a record with an Equivocal Q-code PLUS a 5-1 or 5-2.

ED7. No Q-code and no 9-2 in reference ECG followed by a record with an Equivocal Q-code PLUS a 9-2.

Evolving ST-T Pattern:

EV1. Either 4-0 (no 4-code), 4-4 or 4-3 in reference ECG followed by a record with 4-2 or 4-1-2 or 4-1-1 (confirmed by Significant Increase) OR, for hospital ECGs only, 4-2, 4-1-2 or 4-1-1 in reference ECG followed by a record with 4-0, 4-4 or 4-3 (confirmed by Significant Decrease),
PLUS
either no Q-code in both the reference ECG and the follow-up ECG OR Q-code(s) present in reference ECG or follow-up ECG but no Significant Increase found.

EV2. Either 4-2 or 4-1-2 in reference ECG followed by a record with 4-1-1 (confirmed by Significant Increase) OR, for hospital ECGs only, 4-1-1 in reference ECG followed by a record with 4-2 or 4-1-2 (confirmed by Significant Decrease),
PLUS
either no Q-code in both the reference ECG and the follow-up ECG OR Q-code(s) present in reference ECG or follow-up ECG but no Significant Increase found.

EV3. Either 5-0, 5-4 or 5-3 in reference ECG followed by a record with 5-2 or 5-1 (confirmed by Significant Increase) OR, for hospital ECGs only, 5-2 or 5-1 in reference ECG followed by a record with 5-0, 5-4 or 5-3 (confirmed by Significant Decrease),
PLUS
either no Q-code in both the reference ECG and the follow-up ECG OR Q-code(s) present in reference ECG or follow-up ECG but no Significant Increase found.

EV4. Code 5-2 in reference ECG followed by a record with 5-1 (confirmed by Significant Increase) OR, for hospital ECGs only, 5-1 in reference ECG followed by a record with 5-2 (confirmed by Significant Decrease),
PLUS
either no Q-code in both the reference ECG and the follow-up ECG OR Q-code(s) present in reference ECG or follow-up ECG but no Significant Increase found.

EV5. Code 9-0 in reference ECG followed by a record with 9-2 (confirmed by Significant Increase) OR 9-2 in reference ECG followed by a record with 9-0 (confirmed by Significant Decrease),
PLUS

either no Q-code in both the reference ECG and the follow-up ECG OR Q-code(s) present in reference ECG or follow-up ECG but no Significant Increase found.

Diagnostic ECG:
(any ECG may be used for this classification)

D1. An ECG record with any Diagnostic Q-code (Minn. code 1-1-1 through 1-2-5 plus 1-2-7).

D2. An ECG record with ST-segment elevation code 9-2 PLUS T-wave inversion code 5-1 or 5-2.

Equivocal ECG:
(any ECG may be used for this classification)

E1. An ECG record with an Equivocal Q-code (Minn. code 1-2-8 or any 1-3 code).

E2. An ECG record with ST-segment depression code 4-1-x or 4-2 or 4-3.

E3. An ECG record with T-wave inversion code 5-1 or 5-2 or 5-3.

E4. An ECG record with ST-segment elevation code 9-2.

Other ECG:

O1. Reference ECG coded 7-1-1, 7-2-1, or 7-4.

O2. Any ECG coded 7-1-1, 7-2-1, or 7-4.

O3. Normal ECG(s).

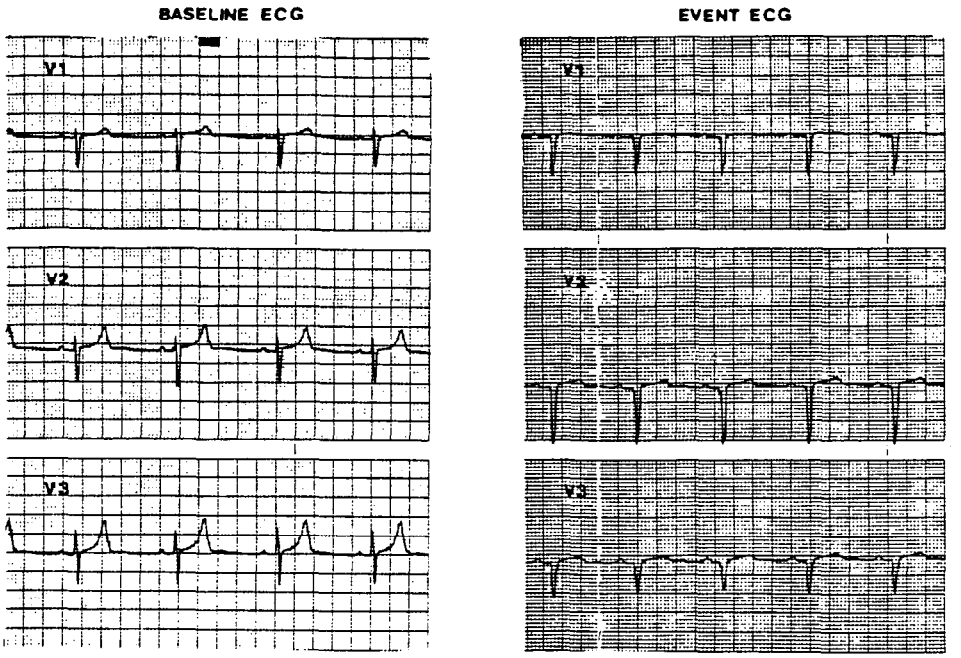
O4. Other findings including 1-2-6.

Uncodable ECG:

U1. Technical errors coded 9-8-1 by Minnesota Code.

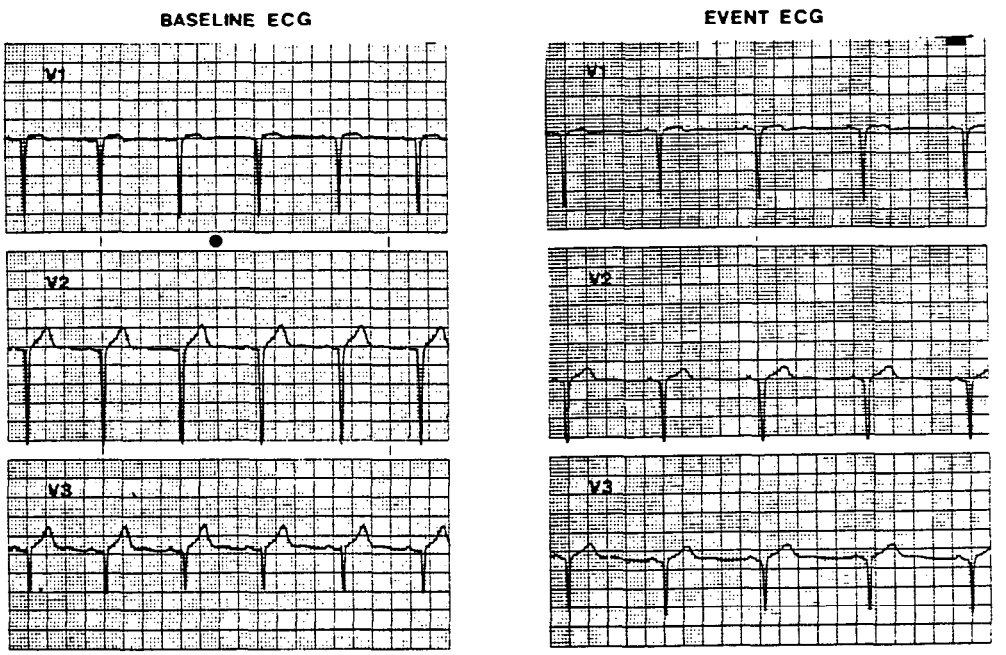
Absent ECG:

A1. No ECG available for coding.



18. Minnesota Code 1-2-7

Baseline ECG shows initial R-waves V_1–V_3. Event ECG shows QS pattern V_1–V_3, making a 1-2-7 code. Significant ECG pattern change IS confirmed because ≥ 1 mm R-wave amplitude decrease occurs between the ECGs in leads V_1–V_3.



19. Minnesota Code 1-2-7

Baseline ECG shows small initial R-waves in V_2 and V_3. Event ECG shows QS pattern V_1–V_3, making a 1-2-7 code. Significant ECG pattern change IS NOT confirmed because < 1 mm R-wave amplitude decrease occurs between the ECGs in V_3. (Note majority of initial R-waves in V_3 at baseline are < 1 mm.)

THE UNIVERSITY OF NORTH CAROLINA
AT
CHAPEL HILL

laborative Studies Coordinating Center
Department of Biostatistics
School of Public Health

CB# 8030, Suite 203, NCNB Plaza
The University of North Carolina at Chapel Hill
Chapel Hill, N.C. 27514-4145

M E M O R A N D U M

TO: ARIC Principal Investigators, Study and Data Coordinators
FROM: ARIC Coordinating Center
DATE: July 15, 1988
SUBJECT: Replacement pages for ARIC Manual 5, Version 1.1

==========

For the above named manual, please replace the title page and the page(s) which are listed on the Revision Log with the enclosed material. Following the instructions in the Revision Log, remove the outdated page(s) in your current manual, file it (them) for future reference, and insert the enclosed pages. To assist you in keeping a permanent record of all procedural changes that are implemented during the study, the footer of each page in the manual is updated to reflect the date the Steering Committee approved the revision and the manual's new version number.

The following changes (typed in CAPS) have been made to Version 1.0.

APPENDIX B. MAC PC ENTRY INFORMATION NEEDED FOR EACH PARTICIPANT.

Page 1. Entry procedures for TOMHS were deleted.

Page 2. Entry procedures for TOMHS were deleted.
RACE: DO NOT LEAVE BLANK. INDICATE RACE.

APPENDIX Q. ECG TECHNICIAN PROCEDURE REVIEW.

Page 1. Two questions were added.

4. Date: __/__/__ (Month/day/year)

5. Quarter: __ January __ April __ July __ October

Pages 2 and 3. The numbering of the questions were changed, several questions were revised or added (see below) and questions 31 (Overall assessment of performance) and 32 (Reasons for assessment listed above) were deleted.

009:man5new.mmo:7/14/88:ccp

1. Subject asked to disrobe to waist only IF BACK-OPENING GOWN WORN.

3. LIMB LEADS CORRECTLY MARKED.

4. Electrode areas wiped with alcohol, THEN WITH A GAUZE PAD.

5. LIMB ELECTRODES PLACED WITH THE TABS IN THE CORRECT POSITION.

6. ELECTRODES MASSAGED IN A SMALL CIRCULAR MOTION.

11. E POINT TO V6 MEASURED WITH TAPE MEASURE AND NOTED ON SCRATCH PAPER.

15. ELECTRODES APPLIED AS IN STEPS 3-6.

23. IF DISPLAY COUNTS PAST 45: REPEAT SKIN PREPARATION USING 2 STROKES WITH FINE SANDPAPER. REPLACE WITH NEW ELECTRODES.

Page 4. Questions originally on page 4 were moved to page 3.

Atherosclerosis Risk in Communities Study Protocol

Manual 5

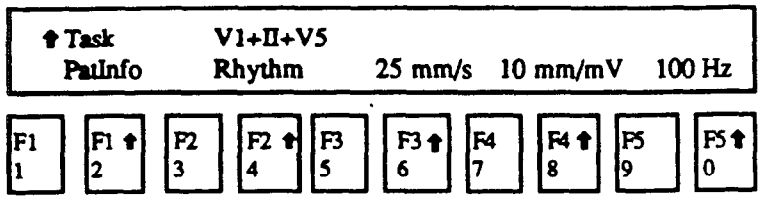
Electrocardiography

For Copies, Please Contact
ARIC Coordinating Center
Department of Biostatistics (CSCC)
CB# 8030
Suite 203, NCNB Plaza
137 E. Franklin Street
Chapel Hill, NC 27514

Version 1.0: August, 1987
Version 1.1: June 1, 1988

MAC PC ENTRY INFORMATION NEEDED FOR EACH PARTICIPANT

After each entry - press return



Press either F1 or F1.

New Patient: Yes No

This won't show up if the machine was just turned on.
Press either F1 button if it is a new person.
Press either F2 button if you want to correct an entry and/or take another ECG on the same person.

Patient, Last Name: A to Z, Space, ', .

Enter first 4 letters of Last Name:
examples: SMIT, JONE, HESS

Patient, First Name: A to Z, 0 to 9, Space, , - , .

Enter complete ID. : MI23456

Patient ID: Digits 0 to 9

Repeat digit portion of ID.: 123456

Referred by (Physician Name)

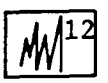
Leave blank.

Location Number: 0 to 99

Enter Contact Year (1,2,etc.)

Room Number: Any 5 Characters

Enter your Technician ID number.

Date of Birth (DD-MMM-YY) DD=Day, MMM=Month Name, YY=Year	To type dash press ▲ and F at the same time. DD=Day (1-31) MMM=LETTERS of month (JAN., FEB., etc.) YY=Year (86, 87, etc.)
Height: 0 to 999	Put in E to V6 distance in cm.
Weight: 0 to 999 lbs.	Put in filter setting at 16.
Sex: Male Female	Indicates sex, Press either F1 or F2.
Race: Cauc Black Oriental Hisp More	DO NOT leave blank Indicate Race
Medication: None Unknown Clr+Add Add Scroll	Leave blank
MAC PC is now ready to take a 12-lead ECG	Press 
Follow directions on screen	Press 
Next take rhythm strip	

ARIC
ECG TECHNICIAN PROCEDURE REVIEW

This form is required for ECG technician certification, recertification and quality control. It is to be completed by the ECG training supervisor by observing the ECG technician taking an ECG recording. The ECG recording should be done on a non-study individual. Quality control observations should occur every three months.

The ECG training supervisor should not make any comments during the recording. The steps outlined below should be done in the order indicated. Any departure from this sequence should be noted in the comments section of the form.

I. Identifying Information

1. Field Center: _____

2. ECG Technician: _____ Tech. No. _____

3. ECG Supervisor: _____ Tech. No. _____

4. Date: ____/____/____ (Month/Day/Year)

5. Quarter: ___ January ___ April ___ July ___ October (19_ _)

ECG Technician Procedure Review (cont'd)

	Yes	No	Comments
1. Subject asked to disrobe to waist only if back-opening gown worn.	( )	( )	_____
2. Subject instructed to lie on the recording bed with arms relaxed at the sides.	( )	( )	_____
3. Limb leads correctly marked.	( )	( )	_____
4. Electrode areas wiped with alcohol, then with a gauze pad.	( )	( )	_____
5. Limb electrodes placed with the tabs in the correct positions.	( )	( )	_____
6. Electrodes massaged in a small circular motion.	( )	( )	_____
7. V2 position correctly marked.	( )	( )	_____
8. V1 position correctly marked.	( )	( )	_____
9. E Point position correctly marked.	( )	( )	_____
10. V6 position correctly marked using chest square.	( )	( )	_____
11. E Point to V6 measured with tape measure and noted on scratch paper.	( )	( )	_____
12. V4 position correctly marked using tape measure.	( )	( )	_____
13. V3 position correctly marked using a flexible ruler.	( )	( )	_____
14. V5 position correctly marked using a flexible ruler.	( )	( )	_____
15. Electrodes applied as in steps 3-6.	( )	( )	_____
16. Appropriate leadwire clipped to each electrode.	( )	( )	_____
17. Participant information entered into the MAC PC according to Appendix 1.	( )	( )	_____
18. Electrodes and leadwires checked.	( )	( )	_____
19. Subject asked to relax, lie quietly.	( )	( )	_____

ECG Technician Procedure Review (cont'd)

		Yes	No	Comments
20.	Electrodes on skin 2-5 minutes before taking ECG.	( )	( )	_____
21.	MAC PC display watched for error messages.	( )	( )	_____
22.	If error message(s): Electrode contacts and leadwires checked, display observed again.	( )	( )	_____
23.	If display counts past 45: Repeat skin preparation using 2 strokes with fine sandpaper. Replace with new electrodes.	( )	( )	_____
24.	ECG tracing removed from the MAC PC.	( )	( )	_____
25.	ECG examined for baseline drift, noise 60-cycle interference and muscle tremor.	( )	( )	_____
26.	When technically inadequate, ECG re-recorded until an acceptable recording is achieved.	( )	( )	_____
27.	Rhythm strip recorded immediately after 12-lead ECG.	( )	( )	_____
28.	Stop watch or watch with second hand used to time two minutes.	( )	( )	_____
29.	Starting time established for two minute strip when the baseline is stable.	( )	( )	_____
30.	Electrodes removed.	( )	( )	_____
31.	The strip folded accordion style.	( )	( )	_____

32. Results reviewed by the ECG technician and supervisor

    a. Signature of ECG technician supervisor _____

    b. Signature of ECG technician _____

THE UNIVERSITY OF NORTH CAROLINA
AT
CHAPEL HILL

Collaborative Studies Coordinating Center
Department of Biostatistics
School of Public Health

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The University of North Carolina at Chapel Hill
Chapel Hill, N.C. 27514-4145

MEMORANDUM

TO: ARIC Principal Investigators, Study and Data Coordinators

FROM: ARIC Coordinating Center

DATE: November 21, 1989

SUBJECT: Replacement pages for ARIC Manual 5, Version 1.2

==========

For the above named manual, please replace the title page and the page(s) which are listed on the Revision Log with the enclosed material. Following the instructions in the Revision Log, remove the outdated page(s) in your current manual, file it (them) for future reference, and insert the enclosed pages. To assist you in keeping a permanent record of all procedural changes that are implemented during the study, the footer of each page in the manual is updated to reflect the date the Steering Committee approved the revision and the manual's new version number.

cc: Woody Chambless
Millicent Higgins
Paul Sorlie

Atherosclerosis Risk in Communities Study Protocol

Manual 5

Electrocardiography

For Copies, Please Contact
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Version 1.0: August, 1987
Version 1.1: June 1, 1988
Version 1.2: June 1, 1989
Version 1.2: September 1, 1989

ARIC
MANUAL OF OPERATIONS REVISION LOG

VOLUME 5: Electrocardiography

The columns in the Log provide documentation of each version change and its implementation date during the course of the study. The Coordinating Center will update columns 1-5 with each distributed update or revision. You are responsible for recording the date on which you update your manual in column 6.

(1)	(2) Description of Revisions			(3)	(4)	(5)	(6)
RVN #	New Version #	New Version Date	For Section #	Pages to be Removed	Pages to be Inserted	Effective Date	Revision Date
1	1.1	6/01/88	Appendix P Appendix Q	A12-13 A60-63	A12-13 A60-62	6/01/88 7/05/88	
2	1.2	9/21/89	2.1 - 2.5	15-20	15-20	9/21/89	

i) The machine will dial the phone and transmit each ECG.
j) Watch the display as each ECG is transmitted and check the IDs on the Directory List. This way if a problem occurs, the ECG involved can be identified.
k) After the last ECG to be transmitted is displayed, a message indicating the number of ECGs that were transmitted vs. the number you selected to transmit is displayed. If the numbers are not the same, the problem ECGs will have been identified on the Directory List. These can be re-transmitted using the above steps.
l) Keep the Directory List available for confirmation from Halifax via electronic mail the next morning.

1.11.2 Confirmation

Every morning the ECG Computer Center in Halifax notifies each field center of the IDs received. Notification is by ARIC electronic mail directly to the field center's personal computer. The mailing includes the ID, date and time of each ECG received on the previous evening.

Compare the Directory List with the IDs of the mailing. If there is more than one ECG in the directory for a participant, compare the qualities and the times. If the ECGs were of equal quality, compare the times to verify that the earliest record was sent and received.

If there is an ID on the Directory (which had been marked for transmission) that is not on the confirmation mailing, retransmit that ID immediately. If there is an ID on the confirmation mailing that is not on your Directory List, notify Halifax of this through ARIC electronic mail.

Note: Confirmation of transmission from Halifax has nothing to do with the confirmed/unconfirmed report settings in the MAC PC.

1.11.3 Deletion

To delete ECGs that have been received by Halifax:

1. From the Main Menu press the shift and F1 simultaneously to show the system functions display.
2. Press the Storage (F1) key to display the storage functions display.
3. Press the Delete (F4) key.
4. Patient data for the first ECG in memory will be displayed.
5. If confirmation from Halifax has been received, press the Delete (F1) key, otherwise press the save (F2) key.
6. Each ECG in the Directory will be displayed. Press Delete or Save for each one.
7. The machine will count the ECGs and the display will ask if you really want to delete them. If you are sure you have selected only ECGs confirmed by Halifax and/or bad quality ECGs, press Yes (F1), otherwise press No (F2) and start over.
8. You may also press Quit (F4) while any ID is being displayed if you have made a mistake and nothing will be deleted.

2. CENTRAL ECG READING BASELINE ECGS

2.1 Resting 12-lead ECG

Reading of 12-lead ECGs by the Halifax ECG Computer Center includes the Minnesota Code (1) (Appendix E) and the Performance Grade Level (Appendix F). Every month Halifax sends these data for the ECGs received in the previous month to the Coordinating Center on diskette (Appendix G). Wave voltage and duration measurements also taken are detailed in Appendix H and include U-wave measurement, the Dalhousie score for left ventricular mass (Appendix I), and the Cardiac Infarction Injury Score (2) (Appendix J). These data are reported at the end of the study.

All resting 12-lead ECG records with the computer-generated ECG findings listed below, and at least a 10% random sample of the remaining ECGs are visually coded at the Minneapolis ECG Reading Center by the full Minnesota code. Minnesota Code criteria are in Appendix E. Results are recorded on the ARIC Cohort 12-lead Resting ECG form (Appendix K), and entered into the local computer database. Periodically, all records created or modified since the previous shipment date are reformatted in conformity with the ARIC Data Transfer Standard and shipped to the Coordinating Center on diskette. The computer ECG codes which require visual coding include:

1. any 1-code,
2. any 4-1, 4-2, 5-1 or 5-2 code,
3. any 9-2, 6-4, 7-1-1 or 7-2-1 code.

Adjudication:

The visual Minnesota Codes are sent to the Coordinating Center for comparison with the computer-generated codes. Adjudication between the visual code and the computer code is performed at the Minnesota Center field-by-field by two electrocardiographers only on ECGs that have a substantial discrepancy (see below) involving the following: (a) any 1-code except 1-2-8, (b) any 4-1 and 4-2, any 5-1 and 5-2, and (c) any 9-2, 6-4, 7-1-1 and 7-2-1. The Coordinating Center determines the IDs that have any of these discrepancies and sends a report form to the Minnesota Coding Center listing the ID, acrostic, date and time of ECG, the visual codes and the computer codes. These ECGs are examined and the adjudicated codes are recorded on a separate version of the 12-lead Resting ECG Form (Appendix K) which is returned to the Coordinating Center. The Coding Center will only report the results of adjudicating the specific variables on which disagreement existed, and will not perform a complete recoding of the ECG. The Coordinating Center adds the adjudicated codes to the data base as the definitive Minnesota Codes for the IDs involved.

Criteria for Agreement:

The Halifax and Minneapolis ECG records will be considered to be in agreement only if they meet the standards for substantial agreement in their coding of each lead group for Q-waves, ST-depression, and T-waves.

Q-codes: The two centers will be considered in substantial agreement if within each lead group,

1. Both centers assign 1-1-x codes.
2. Both centers assign 1-2-x codes.
3. Both centers assign 1-3-x codes.
4. Both centers assign no Q-code.

ST-depression:
Agree if within each lead group,
both code 4-1-x (either 4-1-1 or 4-1-2) or if
both code 4-2, or if
both have any other code

T-waves:
Agree if within each lead group both code 5-1,
or both code 5-2, or both have any other code.

ST-elevation:
Agree if within each lead group both code 9-2
or both code no 9-2 code.

Bundle Branch Block:
Agreement if both have assigned code 7-1-1 or both have assigned 7-2-1, or both centers have assigned no 7-1-1 code or 7-2-1 code.

Wolf-Parkinson-White:
Agreement if both assigned code 6-4 or both assigned no 6-code.

Study Data:

The computer assigned codes will be used as Study Data in all cases except where adjudication results in a code different from the original Halifax code. If the two centers disagree on "minor" codes (i.e., codes other than those listed above), the Halifax reading prevails. Only for "major" codes does the adjudicated reading prevail. Note that the adjudicated code could disagree with both initial codes.

2.2 Two-minute Rhythm Strip

Rhythm strips are coded for arrhythmias on the ARIC Cohort Two Minute Rhythm Strip ECG Coding form (see form Appendix N) at the Minnesota ECG Coding Center. The rhythm strips are stored by field center and ID at the Coding Center.

2.3 Visit Two ECGs

Visit two procedures are the same as for baseline ECGs with the exception that baseline and visit two ECGs are compared and that no rhythm strip is recorded. The procedure for the comparison is as follows.

When two ECGs from different field center visits are available, a determination is made. (To be described in the Visit 2 ECG manual.)

Simultaneous ECG comparison is based on the final Minnesota codes. Serial ECG changes (significant increase, no increase or technical problem) are also determined three times in the Minneapolis coding center; the final categories are adjudicated by a senior coder and added to the ARIC Minnesota Coding and Serial Change Field Center Visit Two ECG form (Appendix M). Serial Change criteria are in Appendix L. These objective rules for side-by-side ECG evaluation are used to determine whether a Minnesota code change between ECG pairs is significant. The simultaneous ECG evaluation procedure uses the first clinic visit ECG as the reference ECG for comparison.

ARIC requires a Minnesota Code change plus agreement by simultaneous ECG comparison before declaring that the ECG pattern change meets ARIC ECG criteria for interim MI (see Appendix V).

A determination that an ARIC participant has had an MI, either prior to the initial clinic visit or between visits, can be made on ECG evidence alone, using the following criteria:

1. Prevalent MI at Baseline
   Baseline ECG (initial cohort visit) coded:
   a) any 1-1-X code
      OR
   b) any 1-2-X PLUS 4-1-1 or 4-1-2 or 4-2 or 5-1 or 5-2.

2. Interim MI Between Cohort Visits
   An Evolving Diagnostic ECG Pattern (ED1 through ED7) between the baseline ECG (initial cohort visit) and an ECG from a later cohort visit confirmed by simultaneous ECG comparison.

2.4 Hospital ECGs for Cohort

Whenever hospital ECGs for cohort participants are obtained after the baseline examination, photocopies of these records (masked at the field center for all information except ID) are sent to the Coding Center and coded by the Minnesota Code. ECGs are read three times, blinded: the final codes are adjudicated by a senior coder. Minnesota Code criteria are in Appendix E.

ECG's for ID's that fit the change criteria (i.e. any pattern ED1 through ED7 or EV1 through EV5, defined above) are examined side-by-side for serial change.

Simultaneous ECG comparison is performed on the final Minnesota codes using the first ECG of the hospitalization as the reference. Serial ECG changes are also determined three times, blinded. Serial change categories are: significant increase, decrease (but not for Q-codes), no change (this implies no increase for Q-codes) or technical problem. The final

categories are adjudicated by a senior coder and added to the Minnesota Coding and Serial Change Hospital ECG form (Appendix O). Serial Change criteria are in Appendix L. These objective rules for side-by-side ECG evaluation are used to determine whether a Minnesota code change between ECG pairs is significant.

As an example, the ARIC protocol defines a new Minnesota code 1-2-7 as a potential ischemic event. Persons with this severity of ECG change will have simultaneous ECG comparison. The ECG comparison procedure (for this case) requires a $\geq$ 1mm R-wave amplitude decrease between corresponding leads of the reference and comparison ECGs. The criteria for 1-2-7 are QS patterns in V1, V2, and V3. If the reference ECG has R-waves that are $\geq$ 1mm tall in V1 or V2 or V3, then when comparing these ECGs side by side, the R-waves in the reference ECG appear to decrease the appropriate amount (at least 1mm) and a "significant increase" is noted on the Appendix O form. If the reference ECG has R-waves < 1mm tall, it cannot fulfill the change criteria and "no change" is noted (see Appendix W).

ARIC requires a Minnesota Code change plus agreement by simultaneous ECG comparison before declaring that the ECG pattern change meets ARIC criteria for an evolving ECG diagnostic pattern.

The coded ECGs are transmitted to the Coordinating Center for storage in the consolidated ARIC database and the ECGs are filed by field center and ID at the Coding Center.

2.5 Community Surveillance ECGs

To be described in the Visit 2 ECG manual.

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