The Electrocardiogram in Epidemiologic Investigations

A New Classification System

HUBERT V. PIPBERGER, M.D., ERNST SIMONSON, M.D., EMIGDIO A. LOPEZ, JR., M.D., MATTHEW A. ARAOYE, M.D., AND HANNA A. PIPBERGER, B.A.

SUMMARY A new coding system for ECG abnormalities was developed, based on Frank's orthogonal ECG leads. In contrast to other systems, such as the Minnesota Code (MC), the new system was based on data collected prospectively in a cooperative study of 5031 records. The records were classified solely on the basis of non-ECG information. A record sample from normal women was also available. The large data base allowed stratification of ECG criteria according to sex and race.

ECG criteria were determined at two levels of sensitivity and specificity. Specificity was 80–100% at the first level and 90–90% at the second.

The new system has fewer criteria than other codes, which leads to reduction of coding errors and coding time. For common problems in differential diagnosis, optional criteria were included. A computer program for automated coding was also developed.

THE ECG is a standard tool in epidemiologic studies of cardiovascular disease. To report ECG findings in uniform, clearly defined terms, Blackburn et al. introduced the Minnesota Code (MC), which has been widely used.

The original MC was based on the more reliable and generally accepted diagnostic criteria known at that time (1960). Little was known then about actual distributions of ECG findings in large populations, and the criteria proved to have a large observer variation. Another serious shortcoming was the lack of information on the effect of constitutional variables on the ECG, which was later studied extensively. Thus, a code based on actual ECG data from large normal and abnormal populations that takes into account differences in ECG findings according to sex and race would be desirable. In the present study, we attempted to take these factors into consideration.

Corrected orthogonal leads have contributed substantially to a better understanding of ECG lead performance and are being used in most of the larger epidemiologic studies. One major advantage of these leads is the substantial data reduction (12 leads vs three leads) without appreciable loss of clinical information. The Frank system has gained greatest popularity and was therefore selected for the new code. Electrodes must be placed as originally described, because so-called modified Frank leads may not be in agreement with the original Frank lead data.

The availability of a large documented ECG library was significant in selecting the Frank lead system for the new code. Based on standardized, ECG-independent clinical information, this library was developed through a Cooperative Study of the Veterans Administration. Eight hospitals participated.

To reduce coding time and coding errors, the new system was kept as simple and convenient as possible.

Material and Methods

The samples used to develop the code are listed in table 1. The selection criteria have been described in detail, but a brief summary will be given here.

The records from normal subjects were obtained from 1049 adult men and 450 adult women. The age and race distributions of these subjects are shown in figure 1. All patients had a complete history, physical examination and routine laboratory tests. All subjects who had diseases that frequently predispose to cardiovascular disease (diabetes mellitus, pulmonary disease, renal disease, hypertension, anemia and collagen or other types of peripheral vascular disease) were excluded.

For left ventricular hypertrophy, the training set consisted of 440 records from patients with sustained hypertension greater than 150/90 mm Hg. This group was considered to have hypertensive cardiovascular disease (HCVD) of moderate degree with cardiac enlargement but without a history of congestive heart failure. Subjects who had a mild and severe HCVD served as test groups. The mild HCVD group consisted of patients who had normal-size hearts and sustained blood pressure elevation. The severe HCVD group had, in addition, a history of congestive heart failure. An additional test group consisted of 211 records from patients with aortic valvular disease.

The group with myocardial infarcts (MI) consisted of 1100 records from patients with a documented history of severe chest pain and typical enzyme elevations. The ECG was not used for case selection, so 44% did not have typical Q-wave abnormalities. This

From the Veterans Administration Medical Center and the Departments of Clinical Engineering and Medicine, George Washington University, Washington, D.C.; the Department of Medicine, Mount Sinai Hospital, and the Laboratory of Physiological Hygiene, University of Minnesota, Minneapolis, Minnesota.

Supported by the Medical Research Service of the Veterans Administration and by NHLBI research grants HL-18850 and HL-17329.

This work was initiated early in 1974 by Dr. Simonson in cooperation with the other authors. After his death on December 7, 1974, they brought the work to its conclusion.

Address for correspondence: Hubert V. Pipberger, M.D., George Washington University Medical Center, 2300 K Street, N.W., Washington, D.C. 20037.

Received February 20, 1981; revision accepted October 19, 1981.
TABLE 1. Number of Cases

<table>
<thead>
<tr>
<th></th>
<th>White</th>
<th>Black</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal males</td>
<td>690</td>
<td>359</td>
<td>1049</td>
</tr>
<tr>
<td>Normal females</td>
<td>309</td>
<td>141</td>
<td>450</td>
</tr>
<tr>
<td>MI</td>
<td>1043</td>
<td>57</td>
<td>1100</td>
</tr>
<tr>
<td>Left ventricular hypertrophy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mild HCVD</td>
<td>250</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate HCVD</td>
<td>440</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Severe HCVD</td>
<td>326</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AS</td>
<td>73</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AI</td>
<td>138</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right ventricular hypertrophy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MS</td>
<td>73</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate COPD</td>
<td>178</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Severe COPD</td>
<td>126</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left ventricular conduction defect</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With MI</td>
<td>234</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without MI</td>
<td>253</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right ventricular conduction defect</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With MI</td>
<td>161</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without MI</td>
<td>180</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5031</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Breakdown of records used for developing and testing of the code. Except for the 450 normal females, all other records were obtained from males.

Abbreviations: HVC = hypertensive cardiovascular disease; AS = aortic stenosis; AI = aortic insufficiency; MS = mitral stenosis; COPD = chronic obstructive pulmonary disease; MI = myocardial infarction.

was partially because the majority had old MIs, in which case Q waves might have disappeared. In some other cases, acute MIs were considered to be subendocardial without typical Q wave changes. Because the 481 records without Q-wave abnormalities could not be classified according to infarct location, discriminant-function analysis, as described by Eddleman and Pipberger, was applied to assign MI as anterior, posterodiaphragmatic or lateral. This resulted in 395, 603 and 102 cases, respectively, for the three MI groups.

The group with chronic obstructive pulmonary disease (COPD) consisted of 304 cases. They were considered to have moderate or severe COPD based on their timed vital capacity (TVC). The group with a more severe degree had a TVC of 25–50% and the moderate group had a TVC of 51–75%.

Because right ventricular hypertrophy (RVH) is the most salient feature in the ECG of COPD, particularly in advanced stages, simple ECG criteria that can be measured by hand cannot differentiate efficiently between RVH and COPD. For the purposes of the code, the two groups were combined and labeled RVH-COPD. The RVH group consisted of 73 patients with pure mitral stenosis documented by rightheart catheterization. The mean pulmonary artery pressure was greater than 30 mm Hg.

The sample with ventricular conduction defects (VCD) was selected on the basis of QRS duration. This was the only ECG item used for case selection. Records in which the QRS interval exceeded the normal limit of 0.12 second in males and 0.11 second in females were considered to have VCDs. Although actual normal limits were 10 msec shorter, these limits were extended because some patients with ventricular hypertrophy show a certain degree of QRS prolongation without representing true conduction defects of the bundle branch block type. The longest QRS complex in any one of the three leads is used for measurements. The VCD sample was subdivided according to the direction of the terminal QRS forces. Those with an anterior and rightward direction were considered to have a right ventricular conduction defect (RVCD) and those with mainly leftward and posterior direction, a left ventricular conduction defect (LVCD).

ECG measurements for the classification code were selected on the basis of their efficiency in discrimination between normal and abnormal and for their practicality. The performance of the ECG criteria was measured by their sensitivity and specificity.

Only ECG items that can be easily obtained by hand were tested. This limits the selection of measurements to time intervals, wave amplitudes and some derived measurements such as amplitude ratios, sums of various amplitudes and similar simple combinations. All items were tested by computer, following the measurement rules and recommendations of the American Heart Association. (fig. 2). Sometimes, more complex variables were more efficient in terms of performance, but for the sake of practicality, they were not included.

Sensitivity for several measurements was always determined cumulatively. For LVH, for instance, a

FIGURE 1. The age distribution of 1049 normal males and 450 females as a percentage of the total of each sex.
limit of 1.9 mV for $R_x$ amplitude was used as the first criterion for white males. In 25% of moderately hypertensive white males, this limit was exceeded, indicating the sensitivity for this single measurement (table 2). At the same time, 4% of the normal control of white males exceeded this limit, representing the false-positive rate (FP). The reciprocal of the FP rate indicates the specificity, which was therefore 96%. The second criterion selected for LVH was the sum of the amplitudes of $R_x$ and $R_z$ with a limit of normal of 2.9 mV. The percentage of LVH cases recognized in addition to the first criterion was 16%, resulting in a cumulative sensitivity for the two criteria of 41%. The FP rate increased at the same time to 6%, leading to a combined specificity of 94%. A third criterion, the duration of the R wave in lead Z, increased the percentage of cases recognized as LVH from 41% to 55%, with a concomitant increase of the FP rate from 6% to 7%, resulting in a cumulative specificity of 93%.

Diagnostic criteria with specified levels of sensitivity and specificity were determined separately for white males, white females, black males and black females.

Not enough cases were available for all abnormal categories (none for females and some small samples for black males), so we assumed that at identical levels of specificity, comparable levels of sensitivity can be expected. Because there were enough records from normal subjects, specificity rates could be shown to be stable. The same stability was found for the large series of abnormal white males.

Atrioventricular (AV) conduction abnormalities and atrial and ventricular arrhythmias are coded in the same fashion for both sexes and races. This part of the code is similar to the MC.

QRS-axis deviations are coded on the basis of R/S ratios in leads X and Y. Normal ranges of QRS-axis direction in orthogonal leads differ from those of the standard 12-lead ECG. Because these criteria were developed from a population of white males and black males, further testing in females is recommended before they are applied routinely. The first differentiation is between LVH and AMI (code 21), which applies to all cases with reduction or loss of anterior QRS forces (abnormally low Q/Rx ratio or loss of Qz).

The second differentiation (code 22) applies to patients with an abnormal QRS shift in anterior direction, which may be due to high posterior MI or RVH. Left septal fascicular block might also have to be considered in this context.

Differentiation between COPD and MI is a frequent problem because COPD can mimic MI with typical Q-wave or Q/R-ratio abnormalities. Criteria were developed for all infarct locations.

One of the most difficult problems is the recognition of MI in the presence of VCDs. Criteria are given both for MI with LVCD and MI with RVCD. They should be applied routinely in all cases with VCD in age groups prone to coronary artery disease.

### Results

The ECG abnormalities included in the code are listed at the beginning of the appendix. A complete listing of the code follows. The normal ECG is characterized by limits of normal for QRS duration and by exclusion of all other codable abnormalities.

Code numbers 2-1 to 2-4 indicate criteria for the
diagnosis of MI with different MI locations. In this and all subsequent listings, criteria A and B represent a relatively higher and lower specificity, respectively. Columns 1 to 4 indicate normal limits for race and sex. There are substantial differences between the two races and somewhat smaller differences between the sexes. When all four criteria were applied to normal subjects older than age 40 years and stratified according to sex and race, cumulative FP rates varied for criteria A from 6–8% and for criteria B from 12–18%. This corresponds to a specificity of 92–94% for criteria A and of 82–88% for criteria B. Sensitivity rates for the various diagnostic criteria will be given in a separate section below.

For the diagnosis of LVH, three criteria were most efficient. The difference between sex and race groups was even more striking, with highest amplitude limits for black males and lowest limits for white females. The second criterion, $R_x + R_{xx'}$, corresponds closely to the Sokolow-Lyon criterion for LVH, in which left-ward and posteriorly directed forces are summed. The cumulative FP rate for LVH varies from 6–8% for criteria A and from 14–18% for criteria B, depending on sex and race. These rates were determined in normal adults of all ages.

The criteria for RVH and COPD were combined. The first four measurements are indicators for both RVH and COPD and the fifth one is more common in COPD. FP rates for the combined RVH-COPD code were 5–8% for criteria A and 11–16% for criteria B.

Codes 5 to 7, dealing with QRS-axis deviations and ST-T abnormalities, are self-explanatory. ST-T changes, similar to other measurements, are classified according to two levels of sensitivity and specificity. Because of the limits of visual resolution and based on tests of reproducibility of hand measurement, accuracy does not appear to exceed 0.5 mm. Therefore, the ST criteria have increments of 0.5 mm.

Code 8 covers VCDs and left ventricular fascicular blocks. For the former, all records with a QRS prolongation are included. Because the normal QRS complex is shorter in women than in men, different limits were used for the two sexes.

The criteria for left ventricular fascicular blocks differ somewhat from those used in the conventional 12-lead ECG because normal ranges for QRS direction are not the same. Left septal fascicular block is also included as an optional code because it is believed to represent a distinct diagnostic entity.

Codes 10 to 12 deal with AV conduction abnormalities, atrial and ventricular rhythms. The various categories were kept relatively simple and are self-explanatory.

Codes 21 to 24 deal with the most common problems in differential diagnosis from the ECG. This part of the code is optional. In most epidemiologic applications, there is probably no need for a detailed differential diagnosis, but in routine clinical applications, this part of the code is useful. It was developed on the basis of many record samples obtained from adult males, both white and black. Limits of the various criteria may need modification for application to females.

Criteria Performance

Because we had many record samples from patients with documentation of the medical diagnosis by non-ECG means, we could test the sensitivity of the criteria for a variety of abnormalities with different degrees of severity. Results of these tests are given in tables 3–5. These data are shown to give some insight into the interdependence of sensitivity and specificity.

The criteria for MI in table 3 cover different MI locations, which occur with different frequencies. The first one, $Q/R_x$, for instance, will be found abnormal mostly with lateral MIs. Because this MI location is less common than anterior or diaphragmatic locations, the sensitivity of this criterion is relatively low (7–9% in our series). It is needed, however, to include

<table>
<thead>
<tr>
<th>Table 3. Myocardial Infarction</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of cases</td>
</tr>
<tr>
<td>Sensitivity</td>
</tr>
<tr>
<td>WM 1043</td>
</tr>
<tr>
<td>BM 57</td>
</tr>
<tr>
<td>Specificity</td>
</tr>
<tr>
<td>WM 690</td>
</tr>
<tr>
<td>BM 359</td>
</tr>
<tr>
<td>WF 309</td>
</tr>
<tr>
<td>BF 141</td>
</tr>
</tbody>
</table>

Sensitivity and specificity for criteria A and B are shown for 1100 patients with myocardial infarction. Sensitivity for black patients is lower than that for whites, but the number of cases is too low to be truly representative.

Abbreviations: WM = white males; WF = white females; BM = black males; BF = black females.

<table>
<thead>
<tr>
<th>Table 4. Left Ventricular Hypertrophy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
</tr>
<tr>
<td>No. of cases</td>
</tr>
<tr>
<td>Hypertensive cardiovascular disease</td>
</tr>
<tr>
<td>Group 1 (mild)</td>
</tr>
<tr>
<td>WM 178</td>
</tr>
<tr>
<td>BM 72</td>
</tr>
<tr>
<td>Group 2 (moderate)</td>
</tr>
<tr>
<td>WM 264</td>
</tr>
<tr>
<td>BM 176</td>
</tr>
<tr>
<td>Group 3 (severe)</td>
</tr>
<tr>
<td>WM 212</td>
</tr>
<tr>
<td>BM 114</td>
</tr>
<tr>
<td>Aortic valve disease</td>
</tr>
<tr>
<td>Aortic stenosis</td>
</tr>
<tr>
<td>WM 73</td>
</tr>
<tr>
<td>Aortic regurgitation</td>
</tr>
<tr>
<td>WM 95</td>
</tr>
<tr>
<td>BM 43</td>
</tr>
</tbody>
</table>

Sensitivity of various criteria for left ventricular hypertrophy is shown for patients with hypertensive cardiovascular disease and aortic valvular disease. Specificity for criteria A was 92–94% and for criteria B, 82–86%.
lateral MIs in the code. A similar situation prevails for the fourth criterion, the upper limit of the Q/R ratio, which applies to so-called high posterior MIs, which are also not very common. When all four criteria are tested on new patients, the total cumulative sensitivity depends largely on the frequency distribution of infarct locations. In the training set of 1100 records from patients with MI, there were 9% with lateral MI, 55% with posterodiaphragmatic MI and 36% with anterior and anteroseptal MI. The total sensitivity for infarcts of all locations in white patients was 71% for criteria A and 75% for criteria B. The specificity was 93% and 87%, respectively. The sensitivity for MI in black patients was lower with 60% and 63% for criteria A and B. The specificity was 92% and 88%, respectively. Whether there is a true difference in sensitivity between white and black patients needs further testing on larger series of blacks. In the present series, there were 95% white and only 5% black MI patients.

Results on sensitivity for LVH are shown in table 4. The sensitivity for the three groups with HCVD was 23%, 55% and 67%, respectively, in white patients with criteria A, and 32%, 52% and 67% in blacks. Using criteria B, the corresponding figures were 43%, 70% and 77% in whites and 38%, 59% and 74% in blacks.

LVH criteria were also tested on a record sample with aortic valvular disease (table 4). All of these patients had left-heart catheterization. Records from white patients with aortic stenosis showed a sensitivity of 66% with criteria A and 74% with criteria B. Corresponding figures for white patients with aortic regurgitation were 88% and 92%. Blacks with the same lesion showed a sensitivity of 74% and 84%, respectively.

Sensitivity for RVH was tested first on a sample of white patients with pure mitral stenosis described earlier (table 5). Sensitivity for criteria A was 53% and for criteria B, 65%.

A record sample from patients with COPD was divided into a moderate and a severe group, which were also described earlier. The sensitivity for white patients in the moderate category was 52% with criteria A and 68% with criteria B. The corresponding figures in the severe group were 58% and 79%, respectively. The number of records available from black patients was too small to be tested.

Comparisons of the Minnesota Code and the Washington D.C. Code

A comparison between the new code and the MC was performed on two large record samples from patients with MI and LVH (tables 6 and 7). Because there is no stratification in the MC according to race or sex, records from white and black males had to be pooled in this comparison. At a specificity of 94% with MC 1-1, the sensitivity for the diagnosis of MI was 49% (table 6). At a similar specificity level of 93%, the Washington D.C. code (WC) gave a sensitivity of 70% (criteria A).

When code 1-2 of the MC is used for MI diagnosis, the specificity decreases to 87%. Criteria B of the new code show the same specificity. With these criteria, a sensitivity of 70% was obtained for the MC, with 75% for the WC. Specificity rates for the MC were reported by Kurihara et al. based on 615 autopsy cases without MI.

In the comparison of the performance of the MC and WC codes in patients with LVH, records from mild, moderate and severe groups of hypertensive patients were used. The sensitivity of the WC exceeded that of the MC by almost 20% (table 7). The specificity was approximately equal (94% and 93% for MC and WC, respectively). Only voltage criteria were used in this comparison.

Discussion

The most important feature of the new code is that it is largely based on actual data distributions of normal and abnormal electrocardiograms and not on generally accepted criteria, which have rarely been tested on sufficiently large and controlled record samples. As in the MC, more than one set of criteria are provided for each diagnostic entity. This feature enhances the code's value, particularly in epidemiologic investigations where different applications may require different levels of specificity.

Major considerations in the development of the new code have been efficiency and ease of application. Compared with the MC, the number of codable items could be considerably reduced, which thereby reduces

<table>
<thead>
<tr>
<th>Table 5. Right Ventricular Hypertrophy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
</tr>
<tr>
<td>No. of cases</td>
</tr>
<tr>
<td>Mitral stenosis</td>
</tr>
<tr>
<td>Chronic obstructive pulmonary disease</td>
</tr>
<tr>
<td>Group 1 (moderate) (TVC 51–75%)</td>
</tr>
<tr>
<td>Group 2 (severe) (TVC 25–50%)</td>
</tr>
</tbody>
</table>

Sensitivity for various criteria for right ventricular hypertrophy is shown for patients with mitral stenosis and chronic obstructive pulmonary disease. Specificity for criteria A was 92–96% and 84–89% for criteria B.

Discussion

The most important feature of the new code is that it is largely based on actual data distributions of normal and abnormal electrocardiograms and not on generally accepted criteria, which have rarely been tested on sufficiently large and controlled record samples. As in the MC, more than one set of criteria are provided for each diagnostic entity. This feature enhances the code's value, particularly in epidemiologic investigations where different applications may require different levels of specificity.

Major considerations in the development of the new code have been efficiency and ease of application. Compared with the MC, the number of codable items could be considerably reduced, which thereby reduces

<table>
<thead>
<tr>
<th>Table 6. Comparison of Minnesota Code with Washington D.C. Code: Myocardial Infarction</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of cases</td>
</tr>
<tr>
<td>Minnesota Code</td>
</tr>
<tr>
<td>Washington D.C. Code</td>
</tr>
</tbody>
</table>

Comparison of the diagnostic performance of the Minnesota and Washington Codes in records from patients with myocardial infarction. The number of cases tested with the Minnesota Code is slightly lower than that for the new code because new cases were added more recently. At higher specificity levels, the performance of the Washington Code exceeds that of the Minnesota code by a substantial margin.
The number of records retained can be shown to be independent of limb electrodes used, and in fact the conventional lead system is more sensitive for left ventricular hypertrophy than the Minnesota Code.

When orthogonal leads are used, one may question whether they contain as much information as the conventional 12-lead ECG. The six standard limb leads can be replaced by two limb leads or orthogonal leads X and Y, because any additional limb leads can be obtained by algebraic additions or subtractions from two independent limb leads. The problem is more complex for the six precordial leads. Experience with many record samples in our laboratory and by others\(^6\) has shown that the clinical information derived from the conventional 12-lead ECG can also be obtained from the orthogonal three-lead ECG. There is not always a one-to-one relationship between these two lead systems, and comparison between the two depends largely on the diagnostic criteria being tested. Diagnostic performance of orthogonal leads has been frequently reported to be superior to that of the 12-leads, mainly because of such differences in criteria. When orthogonal leads became available for clinical applications, emphasis on quantitative analysis had become more prevalent and computers were available for testing and optimizing criteria. Such systematic searches were not feasible when 12-lead criteria were selected, which was largely an empirical process with relatively small test samples.

The preliminary tests of the new code’s performance, together with the comparisons with the MC, appeared satisfactory (tables 6 and 7). For records from patients with myocardial infarcts, the sensitivity of the new code was considerably higher than the MC at a high level of specificity (93%). At a lower level of 87%, the sensitivity of the MC was only slightly lower than that of the WC, with a difference of only 5%.

Greater differences were encountered in the tests on records from hypertensive patients (table 7). At a constant specificity level, the average sensitivity of the new code exceeded that of the MC by approximately 20%, with the largest differences in patients with severe hypertension. A large part of this improvement seems to be due to the stratification of the LVH criteria according to race. Differences in voltage criteria between races and sexes can amount to more than 1 mV (appendix). Further testing of the new code on newly developed test samples is needed, particularly for abnormal female records, which were not available for the code development.

After stratification of criteria according to sex and race, the influence of age became almost negligible. This was surprising, because age had been found to correlate more strongly with ECGs than any other variable.\(^4\) The constitutional variables, such as age, sex and race, may not exert an independent influence on the ECG, and some of these variables may be interrelated.

Like the MC, the new code is primarily intended for epidemiologic applications in which ECG findings must be documented in uniform, clearly defined terms, usually for large populations. Because the code is rather comprehensive, routine clinical application may also be considered. For such applications, one should use only criteria A, which have a higher degree of specificity. The specificity levels indicated in this report apply only to differentiation between normal and one abnormality at a time. When more abnormalities are considered simultaneously, specificity almost always decreases.

A computer program has been developed to provide all necessary ECG measurements for complete record coding. The output lists all ECG variables that exceed the limits indicated in the appendix with appropriate code numbers. The program is a modification of the computer program developed by the Veterans Administration\(^7\) which has been in routine use for almost 10 years.

**Acknowledgment**

The authors gratefully acknowledge the help of Vickie Briggs and Shirley Abernathy in preparing this manuscript.

**References**

APPENDIX

ECG Abnormalities Included in the Code

1. Normal electrocardiogram
2. Myocardial infarction (MI)
3. Left ventricular hypertrophy (LVH)
4. Right ventricular hypertrophy (RVH) and chronic obstructive pulmonary disease (COPD)
5. QRS-axis deviation
6. ST junction (point J) and ST-segment shifts
7. T-wave and QT-interval abnormalities
8. Ventricular conduction defects (LVCD and RVCD), including left ventricular fascicular blocks
9. P-wave abnormalities
10. AV conduction abnormalities
11. Atrial rhythm
12. Ventricular rhythm

Differential Diagnosis

21. Anterior MI vs LVH
22. Posterior MI vs RVH
23. COPD vs MI
24. Ventricular conduction defect (VCD) with MI vs VCD without MI

Normal ECG

I-0 QRS duration < 0.12 second for MALE or < 0.11 second for FEMALE and no other codable items in categories 2 to 12.

Myocardial Infarctions (MI)

(Do not code in presence of ventricular conduction defects 8-1, 8-2 or 8-3.)

<table>
<thead>
<tr>
<th>WM</th>
<th>WF</th>
<th>BM</th>
<th>BF</th>
</tr>
</thead>
<tbody>
<tr>
<td>(-1)*</td>
<td>(-2)</td>
<td>(-3)</td>
<td>(-4)</td>
</tr>
</tbody>
</table>

2-1 Q/Rx ampl ratio

A+ > 0.21
B > 0.19
C > 0.15
D > 0.12

2-2 Q/Ry ampl ratio

A > 0.22
B > 0.20
C > 0.17
D > 0.15

2-3 Q/Rz ampl ratio

A < 0.10
B < 0.05
C < 0.09
D < 0.05

2-4 Q/Ry ampl ratio

A > 1.5
B > 1.2
C > 1.4
D > 1.8

In this and the following tables: *Code numbers specify race and sex. For example, 2-1-1 indicates the Q/Rx amplitude ratio limits for white males.

Limits shown under A indicate specificity ≥ 90% associated with relatively low sensitivity. Limits shown under B indicate specificity of 80–90% associated with higher sensitivity.

Abbreviations: WM = white males; WF = white females; BM = black males; BF = black females.

Left Ventricular Hypertrophy (LVH)*

(Do not code in presence of ventricular conduction defects 8-1, 8-2 or 8-3.)

<table>
<thead>
<tr>
<th>WM</th>
<th>WF</th>
<th>BM</th>
<th>BF</th>
</tr>
</thead>
<tbody>
<tr>
<td>(-1)</td>
<td>(-2)</td>
<td>(-3)</td>
<td>(-4)</td>
</tr>
</tbody>
</table>

3-1 Rx amplitude

A > 1.9
B > 1.7
C > 1.3
D > 1.9
E > 1.7

3-2 Rx + Rz amplitude

A > 2.9
B > 2.7
C > 2.3
D > 2.1

3-3 Rx duration

A > 0.07
B > 0.06

* T-wave abnormalities and ST depression in lead x (codes 7-1-B and 6-1-B) are frequently associated with LVH. If codes 3-1, 3-2 and 3-3 are negative, however; ST and T changes alone are not sufficient for a definite LVH diagnosis, because their specificity is relatively low.

and orthogonal leads. Circulation 27: 58, 1963


24. Sokolow M, Lyon TP: The ventricular complex in left ventricular hypertrophy as obtained by unipolar precordial and limb leads. Am Heart J 37: 161, 1949


Right Ventricular Hypertrophy (RVH) and Chronic Obstructive Pulmonary Disease (COPD)*
(Do not code in presence of ventricular conduction defects 8-1, 8-2 or 8-3.)

<table>
<thead>
<tr>
<th>WM (-1)</th>
<th>WF (-2)</th>
<th>BM (-3)</th>
<th>BF (-4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-1 Rx amplitude</td>
<td>A &lt; 0.4</td>
<td>&lt; 0.3</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>B &lt; 0.5</td>
<td>&lt; 0.4</td>
<td>&lt; 0.5</td>
<td>&lt; 0.6</td>
</tr>
<tr>
<td>4-2 R/Sx amplitude ratio</td>
<td>A &gt; 1.1</td>
<td>&gt; 0.9</td>
<td>&gt; 1.0</td>
</tr>
<tr>
<td>B &gt; 1.2</td>
<td>&gt; 1.5</td>
<td>&gt; 1.5</td>
<td>&gt; 2.0</td>
</tr>
<tr>
<td>4-3 Q/Rx amplitude ratio</td>
<td>A &gt; 1.5</td>
<td>&gt; 1.6</td>
<td>&gt; 1.5</td>
</tr>
<tr>
<td>B &gt; 1.3</td>
<td>&gt; 1.5</td>
<td>&gt; 1.5</td>
<td>&gt; 1.5</td>
</tr>
<tr>
<td>4-4 Rx amplitude</td>
<td>A &lt; 0.3</td>
<td>&lt; 0.2</td>
<td>&lt; 0.4</td>
</tr>
<tr>
<td>B &lt; 0.4</td>
<td>&lt; 0.3</td>
<td>&lt; 0.4</td>
<td>&lt; 0.3</td>
</tr>
<tr>
<td>4-5 P/Rx amplitude ratio†</td>
<td>A &gt; 0.40</td>
<td>&gt; 0.40</td>
<td>&gt; 0.40</td>
</tr>
<tr>
<td>B &gt; 0.30</td>
<td>&gt; 0.35</td>
<td>&gt; 0.25</td>
<td>&gt; 0.40</td>
</tr>
</tbody>
</table>

*Flat or upright T waves and ST elevations in lead Z (codes 7-3-B and 6-6-B) are frequently associated with RVH and COPD. If codes 4-1 to 4-5 are negative, however, ST and T changes alone are not sufficient for a definite diagnosis of RVH or COPD, because their specificity is relatively low.
†To be coded only in the presence of code 9-2 and the absence of code 2-2; code 4-5 should be omitted when screening for RVH only.

QRS-axis Deviation
(Do not code in presence of ventricular conduction defects and fascicular blocks 8-1 to 8-6.)

Male, female, white and black (-1, -2, -3 and -4)

5-1 Left
R/Sy amplitude ratio < 1.0 and R/Sx amplitude ratio ≥ 1.0.
5-2 Right
R/Sx amplitude ratio < 1.0 and R/Sy amplitude ratio ≥ 1.0.
5-3 Indeterminate
R/Sy amplitude ratio < 1.0 and R/Sx amplitude ratio ≥ 1.0.

ST Junction (Point J) and ST-segment Shifts
(Do not code in presence of ventricular conduction defects 8-1, 8-2 or 8-3.)

Male and female White and black (-1 and -3) Female white and black (-2 and -4)

Depression
6-1 Jx depression and ST segment horizontal or downward sloping A < -0.20 | < -0.20 | B < -0.10 | < -0.10
6-2 Jy depression and ST segment horizontal or downward sloping A < -0.20 | < -0.20 | B < -0.10 | < -0.10
6-3 Jz A < -0.25 | < -0.20 | B < -0.15 | < -0.10

Elevation
6-4 Jx A > 0.20 | > 0.20 | B > 0.10 | > 0.10
6-5 Jy A > 0.20 | > 0.20 | B > 0.10 | > 0.10
6-6 Jz elevation and ST segment horizontal or upward sloping A > 0.15 | > 0.15 | B > 0.05 | > 0.05

T-wave and QT-interval Abnormalities
(Do not code in presence of ventricular conduction defects 8-1, 8-2 or 8-3.)

<table>
<thead>
<tr>
<th>Male and female</th>
<th>White and black</th>
</tr>
</thead>
<tbody>
<tr>
<td>WM (-1)</td>
<td>WF (-2)</td>
</tr>
<tr>
<td>7-1 Tx amplitude</td>
<td>A &lt; -0.3</td>
</tr>
<tr>
<td>7-2 Ty amplitude</td>
<td>A &lt; -0.3</td>
</tr>
<tr>
<td>7-3 Tz amplitude</td>
<td>A &gt; 0.3</td>
</tr>
<tr>
<td>7-4 QT ratio* shortened</td>
<td>A ≤ 0.8</td>
</tr>
<tr>
<td>7-5 QT ratio prolonged A ≥ 1.2</td>
<td>B ≥ 1.1</td>
</tr>
</tbody>
</table>

*QT ratio = \( \frac{QT}{0.4 \sqrt{RR}} \)

Ventricular Conduction Defects Including Left Ventricular Fascicular Blocks
(Do not code 8-1, 8-2 or 8-3 in presence of Wolff-Parkinson-White syndrome, 10-7 or artificial pacemaker.)

8-1 Left Ventricular Conduction Defect
QRS duration ≥ 0.12 second for male or ≥ 0.11 second for female.
QR or R configuration in lead Z and Sx amplitude < 15% of preceding Rx amplitude.

8-2 Right Ventricular Conduction Defect
QRS duration ≥ 0.12 second for male or ≥ 0.11 second for female.
S wave in leads X and Z or QS configuration in lead Z.

8-3 Indeterminate Ventricular Conduction Defect
QRS duration ≥ 0.12 second for male or ≥ 0.11 second for female.
(in absence of 8-1 or 8-2)

8-4 Left Anterior Fascicular Block
(Do not code in presence of RVH, COPD or diaphragmatic infarction, 4-1-B, 4-2-B, 4-3-B, 4-4-B, 4-5-B or 2-2-B.)
R/Sv amplitude ratio < 1.0*
QRS duration < 0.12 second for male or < 0.11 second for female.

8-5 Left Posterior Fascicular Block
(Do not code in presence of RVH, COPD or lateral infarction, 4-1-B, 4-2-B, 4-3-B, 4-4-B, 4-5-B or 2-1-B.)
R/Sx amplitude ratio ≥ 1.0 and R/Sy amplitude ratio < 1.0.
QRS duration < 0.12 second for male or < 0.12 second for female.

8-6 Left Septal Fascicular Block†
(Do not code in presence of RVH, COPD or high posterior infarction, 4-1-B, 4-2-B, 4-3-B, 4-4-B, 4-5-B or 2-4-B.)
Q/Rs amplitude ratio > 1.5 for male or > 2.0 for female.
QRS duration < 0.12 second for male or < 0.12 second for female.

*The limits of normal for QRS direction in the frontal plane (0°) are different from those of the standard limb leads (−30°).
†This abnormality is not routinely used by all electrocardiographers. Code 8-6 should therefore remain optional.
P-wave Abnormalities
(Do not code in presence of ectopic rhythms, 11-5 and 11-7 through 11-10.)

<table>
<thead>
<tr>
<th>9-1 Sum of positive Pz amplitude and positive Pz amplitude</th>
<th>&gt; 0.15</th>
</tr>
</thead>
</table>

Right atrial overload

<table>
<thead>
<tr>
<th>WM (-1)</th>
<th>WF (-2)</th>
<th>BM (-3)</th>
<th>BF (-4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

AV Conduction Abnormalities
Male, female, white and black (-1, -2, -3 and -4)

<table>
<thead>
<tr>
<th>10-1 First-degree AV block (PR interval &gt; 0.21 second in any lead).</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>10-2 Type I: progressive PR interval prolongation followed by a dropped beat (Wenckebach).</td>
<td></td>
</tr>
<tr>
<td>10-3 Type II: constant PR interval duration (normal or prolonged) with occasional dropped beats.</td>
<td></td>
</tr>
<tr>
<td>10-4 Advanced AV block (two or more regular successive P waves are not followed by QRS complex).</td>
<td></td>
</tr>
<tr>
<td>10-5 AV dissociation without complete block.</td>
<td></td>
</tr>
<tr>
<td>10-6 Complete AV block.</td>
<td></td>
</tr>
<tr>
<td>10-7 Preexcitation syndrome, Wolff-Parkinson-White (PR interval &lt; 0.12 second and QRS duration ≥ 0.12 second for male or ≥ 0.11 second for female).</td>
<td></td>
</tr>
<tr>
<td>10-8 Short PR interval (&lt; 0.12 second).</td>
<td></td>
</tr>
</tbody>
</table>

Atrial Rhythm
Male, female, white and black (-1, -2, -3 and -4)

| 11-1 Normal sinus rhythm (≥ 60 and < 100 beats/min). |  |
| 11-2 Sinus arrhythmia (RR change of > 10% of RR interval of adjacent sinus beats). |  |
| 11-3 Sinus tachycardia (≥ 100 beats/min). |  |
| 11-4 Sinus bradycardia (< 60 beats/min). |  |
| 11-5 Wandering atrial pacemaker. |  |
| 11-6 Atrial premature complexes. |  |
| 11-7 Paroxysmal supraventricular tachycardia. |  |
| 11-8 Atrial flutter. |  |
| 11-9 Atrial fibrillation. |  |
| 11-10 AV junctional rhythm. |  |

Ventricular Rhythm
Male, female, white and black (-1, -2, -3 and -4)

| 12-1 Ventricular premature complexes (occasional). |  |
| 12-2 Ventricular premature complexes (10% or more of recorded beats). |  |
| 12-3 Ventricular tachycardia. |  |
| 12-4 Ventricular fibrillation. |  |
| 12-5 Accelerated idioventricular rhythm. |  |
| 12-6 Artificial pacemaker rhythm. |  |

Differential Diagnosis
(Applicable Only to Males)

Anterior MI vs LVH
This differentiation needs to be made when initial anteriorly directed electromotive forces are decreased or absent, i.e., only in presence of code 2-3 A or B.
If 21-1 or 21-2 is exceeded, the record is suggestive of LVH and code 2-3 should be deleted. If both measurements are below these limits, the probability of anterior MI is greater and code 2-3 remains unchanged.
21-1 Rx amplitude ≥ 1.2
21-2 Rx + Rz amplitude ≥ 2.5

High Posterior MI vs RVH/COPD
This differentiation needs to be made when there is an abnormal shift of the QRS complex in anterior direction, i.e., only in presence of codes 2-4 A or B (high posterior MI) and 4-3 A or B (RVH/COPD).
If codes 22-1 and 22-2 are exceeded, the record is suggestive of high posterior MI and code 4-3 should be deleted. When 22-1 is below and 22-2 above the indicated limits, the probability of RVH/COPD is greater, code 4-3 remains unchanged and 2-4 should be deleted.
22-1 Q/Rx amplitude ratio > 0.25
22-2 Tp amplitude < 0.0

COPD vs Myocardial Infarction
This differentiation needs to be made when the record is both compatible with MI and COPD, i.e., when any of the codes 2-1 through 2-3 and 4-1 through 4-5 are positive. The differentiation is divided according to infarct location (2-1 = lateral MI; 2-2 = posterodiaphragmatic MI; 2-3 = anterior).
If any of the measurements 23-1 through 23-8 are below the indicated limits, the record is suggestive of COPD and codes 2-1 through 2-3 should be deleted. When the measurements are above the limits, the probability of infarct is greater and COPD and MI may coexist.
COPD vs lateral MI
23-1 Rx peak time < 0.03
23-2 Q/Rx amplitude ratio < 0.2

COPD vs posterodiaphragmatic MI
23-3 Rx peak time < 0.03
23-4 Rx amplitude < 0.4
23-5 Q/Rx amplitude ratio < 0.10

COPD vs anterior MI
23-6 Rx + Rz amplitude < 1.0
23-7 Rx duration < 0.04
23-8 R/Sx amplitude ratio < 1.4

Ventricular Conduction Defects (VCD) with MI vs VCD without MI
This differentiation needs to be made in all cases with VCD who are in an age group where coronary artery disease may be expected.
If one of the following limits is exceeded, the diagnosis of VCD with MI can be made. Different criteria apply to LVCD and RVCD.
LVCD
24-1 Q/Rx amplitude ratio > 0.19
24-2 Q/Rx amplitude ratio > 0.22
RVCD
24-3 Q/Rx amplitude ratio > 0.19
24-4 Q/Rx amplitude ratio > 0.22
24-5 Q/Rx amplitude ratio < 0.10
The electrocardiogram in epidemiologic investigations. A new classification system.
H V Pipberger, E Simonson, E A Lopez, Jr, M A Araoye and H A Pipberger

Circulation. 1982;65:1456-1464
doi: 10.1161/01.CIR.65.7.1456

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1982 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/65/7/1456

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at: http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation is online at: http://circ.ahajournals.org//subscriptions/