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# THE ELECTROCARDIOGRAM IN EPIDEMIOLOGICAL STUDIES

## REPRODUCIBILITY, VALIDITY, AND INTERNATIONAL COMPARISON

BY

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The means available for identifying coronary disease in the community are regrettably limited. A history of chest pain may be elicited and judicious questions may enable one to decide if this was cardiac or not. If cardiac pain has been experienced, clinical examination may reveal conditions other than coronary disease (congenital, valvular, or hypertensive disease, for example) which could be responsible. Finally an electrocardiogram (ECG) may be taken. If the resting ECG is normal, evidence suggestive of coronary disease may be obtained in a proportion of cases by repeating it under some form of stress, usually exercise. Unfortunately abnormal electrical patterns shown by the ECG, even when they are highly suggestive, are not specific for coronary disease. Furthermore, there may be considerable difficulty in differentiating normal from abnormal tracings (Simonson, 1958). It is not surprising, therefore, that a number of studies have revealed variation between different observers in their classification of ECGs as normal or abnormal and especially of whether the abnormality is due to coronary disease or not (Davies, 1958; Thomas, Cochrane, and Higgins, 1958; Segall, 1960; Acheson, 1960; Epstein, Doyle, Pollack, Pollack, Robb, and Simonson, 1961; Higgins, Cochrane, and Thomas, 1963). Despite these reservations, however, the ECG remains a valuable screening tool for coronary disease. It is objective, simple, rapidly obtained, and painless, and largely independent of co-operation or language differences.

Variation in interpretation of an ECG for coronary disease may arise either because certain items in the tracing are recorded by some observers but not by others, or because of differences of opinion on the meaning of items which have been observed by all. Resolution of observer variation into its two component parts, namely that of observation and that of interpretation, is the logical approach. To do this, Blackburn, Keys, Simonson, Rautaharju, and Punsar (1960) suggested a detailed classification of electrocardiograms based on precisely defined criteria (Appendix). Wherever possible these criteria are determined by objective measurements. This standardized coding system has become known as the Minnesota Code and it has been widely recommended for initial classification of ECGs for epidemiological purposes. A World Health Organization scientific study group on comparable methodology for the epidemiological study of hypertension and ischaemic heart disease (WHO, April 6, 1963) endorsed this approval and advocated studies of the Code's reproducibility and validity. Its validity, the report suggested, might be best established by correlating the ECG code items with the presence or development of disease detected by other means.

The main purpose of the present study was to determine the implication of the various code items as measures of risk of developing or dying of coronary disease. In the course of the work some observations were also made on the reproducibility of the classification and these have been included in the paper. Finally, the use of the code for comparing the frequency of ECG abnormalities in different populations is briefly considered.

The implication of ECG items can be assessed by following a sufficiently large group of people, whose ECGs have been recorded, for 5 to 10 years. Studies of this kind, in which the Minnesota Code has been used, are in fact in progress in various countries and they will in time provide the required information. In the meantime, however, the possibility of obtaining results from one of the prospective cardiovascular studies now in progress seemed worthwhile. The Framingham Heart Project was thought to offer the best available means of carrying this out. For the past 10 years, in order to assess the importance of various factors in the development of heart disease, a sample of the population of Framingham, Massachusetts, has been followed. Full examinations including electrocardiography have been carried out every 2 years and records of morbidity and mortality are very complete for a period of 8 years after the initial examinations. Details of the population sampled, methods used and diagnostic criteria and results have been given in previous publications (Dawber, Meadors, and Moore, 1951; Kannel, Dawber, Kagan, Revotskie, and Stokes, 1961; Dawber, Kannel, Revotskie, and Kagan, 1962).

Briefly, the diagnostic criteria include:

(1) A definite history and/or definite electrocardiographic evidence of myocardial infarction;

(2) Definite angina pectoris;

(3) Sudden death under circumstances suggesting coronary heart disease.

## Method of Procedure

During the summer of 1962 all the ECGs taken at the first examination of the Framingham study were read and classified according to the Minnesota Code. The classification of the tracings was made in ignorance of the age, sex, anthropometric, and other characteristics and clinical state of the person whose tracing was being read. All the tracings were read by one observer (I.T.T.H.) to eliminate the observer differences in classification which may occur even when this code is used. A comparison of coding of a small number of electrocardiograms between I.T.T.H. and Dr Henry Blackburn was made before carrying out the main study. Intra-observer variation was measured by classifying 440 ECGs on two occasions. Validation of the ECG items was attempted first on the basis of mortality over the follow-up period of 8 years, and secondly by using two indices of morbidity; prevalence, or those considered to have coronary disease at the first examination, and incidents of coronary disease (incidence cases and sudden death) during the 8-year follow-up. At the initial Framingham examination, in order to ensure that the population being followed exluded all cases of established coronary disease, a low level of diagnosis of "coronary disease" was adopted. Some cases in which the diagnosis was doubtful may therefore have been included in this group. Over 85 per cent. of the sample seen initially have been followed for 8 years and some information is available for nearly all of those who have moved elsewhere. The 8-year follow-up was based, therefore, on knowledge of over 98 per cent. of the sample.

Deaths are classified broadly by cause as sudden death, other death attributed to coronary disease, and non-coronary death. All clinical information and if the death occurred in hospital, hospital records were used in making this classification; incidents of coronary disease included angina pectoris, myocardial infarction, and sudden death. The diagnostic criteria have been given in the papers already quoted.

## Results

### Reproducibility

*Comparison of Two Observers*

A comparison of classification of 31 ECGs read by I.T.T.H. and Dr Blackburn is shown in Table I (opposite).

These 31 ECGs were taken from cases of coronary disease. They had been assembled to illustrate specific code items, particularly Q wave criteria. Considerable differences are apparent for certain items. For example, Blackburn recorded intraventricular block and other abnormalities of the QRS complex more frequently than I.T.T.H. The agreement however, for the broad categories, Q wave abnormalities, ST depression, and T wave changes, either inversion or flattening (Code items I, IV, V) was fairly good.

*Comparison of One Observer on Two Occasions*

Table II (opposite) shows that, of 440 ECGs read on two occasions, 239 were classified as showing no recordable items each time. Similarly, 169 were classified as having one or more reportable items on both occasions. 22 were called normal on the first occasion but abnormal on the second. Ten were called abnormal on the first and normal on the second. In 108 of the 169 abnormal tracings, the coding was identical on both occasions; in 61 it differed. Including the 32 classified differently on the first and second readings with respect to normality or abnormality, there were 93 of the 440 tracings in which the readings differed to some extent on the two occasions. Q wave items ($I_{123}$) were noted in twenty ECGs, in eighteen of them on both readings; ST depression ($IV_{123}$) was recorded in 23 ECGs, in sixteen on both readings; T wave changes ($V_{123}$) were recorded in 48 ECGs, in 31 on both readings. Measurements* made on the ECGs on the second occasion indicated

* Width and depth of Q; magnitude of R, S, and T in all leads; height of P, P-R interval in lead 2.

TABLE I

COMPARISON OF 31 ECGs READ BY TWO OBSERVERS ACCORDING TO THE MINNESOTA CODE

| No. | I.T.T.H. | | | | | | | | H.B. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | — | — | — | — | $V_{2}$ | — | — | — | — | — | — | — | $V_{3}$ | — | — | — | — |
| 2 | $I_{1}$d | — | — | — | $V_{3}$ | — | — | — | $I_{1}$d | — | — | — | $V_{3}$ | — | — | — | — |
| 3 | $I_{1}$a | — | — | — | $V_{2}$ | — | — | — | $I_{1}$a | — | — | — | $V_{2}$ | — | — | — | — |
| 4 | $I_{1}$d | — | — | $IV_{2}$ | $V_{2}$ | — | — | — | $I_{2}$d | — | — | $IV_{2}$ | $V_{2}$ | — | — | $IX_{3}$ | — |
| 5 | $I_{1}$b(or *f*) | — | — | — | — | — | — | — | $I_{1}$f | — | — | — | — | — | — | $IX_{1}$ | — |
| 6 | $I_{1}$f | — | — | — | $V_{1}$ | — | — | — | $I_{1}$f | — | — | — | $V_{2}$ | — | — | $IX_{1}$ | $IX_{3}$ |
| 7 | $I_{1}$d | — | — | — | $V_{2}$ | — | — | — | $I_{2}$d | — | — | — | — | — | — | $IX_{2}$ | — |
| 8 | $I_{1}$b | — | — | $IV_{3}$ | $V_{3}$ | — | — | — | $I_{1}$d | — | — | $IV_{3}$ | $V_{3}$ | — | — | $IX_{1}$ | — |
| 9 | $I_{1}$g | — | — | — | $V_{2}$ | — | — | — | $I_{1}$g | — | — | — | $V_{2}$ | — | — | — | — |
| 10 | $I_{1}$a | — | — | — | $V_{2}$ | — | — | — | $I_{1}$a | — | — | — | $V_{2}$ | — | — | — | — |
| 11 | — | $II_{1}$ | — | $IV_{1}$ | — | $VI_{1}$ | — | — | — | $II_{1}$ | — | — | — | $VI_{2}$ | $VII_{4}$ | — | — |
| 12 | — | $II_{1}$ | — | $IV_{3}$ | $V_{2}$ | — | — | $IX_{3}$ | — | $II_{1}$ | — | — | — | — | $VII_{4}$ | — | — |
| 13 | $I_{1}$d | — | — | $IV_{3}$ | $V_{2}$ | — | — | — | $I_{1}$d | — | — | — | — | — | $VII_{4}$ | — | — |
| 14 | $I_{1}$d | — | — | — | $V_{2}$ | — | — | — | $I_{1}$a | — | — | — | $V_{2}$ | — | — | — | — |
| 15 | $I_{1}$b | — | $III_{1}$ | — | $V_{3}$ | — | $VII_{3}$ | — | $I_{1}$a | — | — | $IV_{3}$ | — | — | $VII_{3}$ | — | — |
| 16 | $I_{1}$d | — | $III_{1}$ | $IV_{1}$ | $V_{2}$ | — | — | — | $I_{1}$d | — | $III_{1}$ | $IV_{1}$ | $V_{2}$ | — | — | — | — |
| 17 | $I_{1}$d | — | — | $IV_{1}$ | $V_{3}$ | — | — | — | $I_{1}$d | — | — | $IV_{1}$ | $V_{2}$ | — | — | — | — |
| 18 | — | — | — | $IV_{3}$ | $V_{3}$ | — | — | — | — | — | — | $IV_{2}$ | $V_{3}$ | — | — | — | — |
| 19 | — | — | — | $IV_{3}$ | $V_{3}$ | — | — | — | — | — | — | $IV_{2}$ | $V_{3}$ | — | — | — | — |
| 20 | — | — | — | — | $V_{3}$ | — | — | — | — | — | — | — | $V_{3}$ | — | — | — | — |
| 21 | — | — | — | — | $V_{1}$ | — | — | — | — | — | — | — | $V_{1}$ | — | — | — | — |
| 22 | — | $II_{1}$ | — | — | $V_{2}$ | — | — | — | — | $II_{1}$ | — | — | $V_{2}$ | — | — | — | — |
| 23 | — | — | — | — | $V_{3}$ | $VI_{2}$ | — | — | — | — | — | — | — | $VI_{3}$ | — | $IX_{2}$ | — |
| 24 | $I_{2}$h | — | — | — | $V_{3}$ | — | — | — | $I_{1}$f | — | — | — | $V_{3}$ | — | — | — | — |
| 25 | — | — | — | — | $V_{2}$ | — | — | — | — | — | — | — | $V_{2}$ | — | — | $IX_{3}$ | — |
| 26 | $I_{2}$c | — | — | — | $V_{3}$ | — | — | — | $I_{2}$c | — | — | — | $V_{2}$ | — | — | — | — |
| 27 | $I_{1}$g | — | — | — | $V_{2}$ | — | — | — | $I_{1}$g | — | — | — | $V_{2}$ | — | — | $IX_{1}$ | — |
| 28 | $I_{1}$f | — | — | — | — | — | — | — | $I_{1}$f | — | — | — | — | — | — | — | — |
| 29 | $I_{1}$g(b) | $II_{1}$ | — | — | $V_{3}$ | — | — | — | $I_{1}$a | $II_{1}$ | — | — | $V_{3}$ | — | — | — | — |
| 30 | $I_{1}$f | — | — | — | $V_{2}$ | — | — | — | $I_{1}$f | — | — | — | $V_{2}$ | — | — | $IX_{1}$ | — |
| 31 | $I_{1}$f | — | — | — | $V_{3}$ | — | — | — | $I_{1}$f | — | — | — | — | — | — | $IX_{1}$ | $IX_{2}$ |

TABLE II

REPRODUCIBILITY OF MINNESOTA CODE
COMPARISON OF CLASSIFICATION OF 440 ECGs READ BY ONE OBSERVER ON TWO OCCASIONS

| First Reading | | Normal | Abnormal | Total |
|---|---|---|---|---|
| | Normal | 239 | 10 | 249 |
| Second Reading | Abnormal | 22 | 169 | 191 |
| | Total | 261 | 179 | 440 |

In 108 of the 169 abnormal readings the coding was the same; in 61 it differed.

TABLE III

REPRODUCIBILITY OF MINNESOTA CODE
COMPARISON OF CLASSIFICATION OF 43 ECGs BASED ON DETAILED MEASUREMENTS

| First Reading | | Normal | Abnormal | Total |
|---|---|---|---|---|
| | Normal | 17 | 0 | 17 |
| Second Reading | Abnormal | 0 | 26 | 26 |
| | Total | 17 | 26 | 43 |

In 22 of the 26 abnormal readings the coding was the same; in four it differed.

clearly how the tracings should have been classified. They were not, however, always correctly classified and some of the observer variation was due to avoidable error.

In a further study of observer variation based on measurements, 43 of the 440 ECGs were measured and classified according to the Minnesota Code on two occasions. Table III shows that the classification into normal and abnormal by measurement was excellent, but that in four of the 26 abnormal tracings the two readings differed.

*Frequency of ECG Items*

Table IV (overleaf) shows the frequency of certain Minnesota Code items by age and sex. No attempt has been made in this Table to eliminate overlap due to the occurrence of several items in one ECG. The infrequency of the grosser abnormalities, particularly of large Q waves, ST depression, and T wave inversion, often associated with coronary heart disease, is apparent. Flat T waves on the other hand were relatively common. The frequency of most items increased with age. Large Q/QS items ($I_1$), left axis deviation ($II_1$), high amplitude R waves ($III_1$), and the highest grade ST depression ($IV_1$) appeared to be somewhat commoner in men. Intermediate and small Q/QS items ($I_2$ and $I_3$), other grades of ST depression ($IV_2$ and $_3$), and T wave inversion ($V_1$ and $_2$) appeared to be equally frequent in the two sexes. Flat T waves ($V_3$) were possibly slightly commoner in women. Within the Q items ($I_1$ and $_2$), the sub-categories suggested that a higher proportion of men had changes compatible with an anterior infarction. Thus eleven men (78·6 per cent. of those classified as $I_1$), but no women, were coded as $I_{1a}$, $_b$, or $_c$, and eight men (28·6 per cent. of those classified as $I_2$) and three women (9·1 per cent.) were coded as $I_{2a}$, b, or c. On the other hand, a higher proportion of women had either changes suggestive of posterior infarction ($I_{1d}$) or decreasing R wave amplitude across the precordium ($I_{2h}$). The numbers are small but further observation on these sub-categories in the two sexes seems desirable.

## VALIDITY

### *8-Year Mortality according to Initial ECG*

Table V shows the number of deaths, for men and women respectively, which occurred in the 8-year follow-up period according to the initial Minnesota Code classification. Deaths from all causes, deaths occurring suddenly (within one hour

TABLE

FREQUENCY OF CERTAIN MINNESOTA CODE ITEMS BY AGE AND

| Sex | Age (yrs) | No. of ECGs Read | No. with Recordable Item | Q Waves | | | Axis Deviation | High Amplitude R Waves |
|---|---|---|---|---|---|---|---|---|
| | | | | $I_1$ | $I_2$ | $I_3$ | $II_1$ | $III_1$ |
| Male | 30– | 391 | 120 | — (—) | 3 (0·8) | — (—) | 6 (1·5) | 31 (7·9) |
| | 35– | 441 | 138 | — (—) | 3 (0·7) | 3 (0·7) | 6 (1·4) | 30 (6·8) |
| | 40– | 421 | 145 | 1 (0·2) | 5 (1·2) | 1 (0·2) | 7 (1·7) | 29 (6·9) |
| | 45– | 358 | 113 | — (—) | 3 (0·8) | — (—) | 16 (4·5) | 22 (6·1) |
| | 50– | 373 | 131 | 7 (1·9) | 2 (0·5) | 3 (0·8) | 17 (4·6) | 30 (8·0) |
| | 55– | 277 | 113 | 5 (1·8) | 9 (3·2) | 1 (0·4) | 19 (6·8) | 32 (11·6) |
| | 60–62 | 75 | 37 | 1 (1·3) | 3 (4·0) | — (—) | 2 (2·7) | 8 (10·7) |
| | Total .. | 2,336 | 797 | 14 (0·6) | 28 (1·2) | 8 (0·3) | 73 (3·1) | 182 (7·8) |
| Female | 30– | 454 | 90 | 1 (0·2) | 1 (0·2) | — (—) | 4 (0·9) | 6 (1·3) |
| | 35– | 583 | 134 | — (—) | 4 (0·7) | — (—) | 8 (1·4) | 4 (0·7) |
| | 40– | 513 | 136 | 1 (0·2) | 7 (1·4) | 1 (0·2) | 5 (1·0) | 5 (1·0) |
| | 45– | 450 | 122 | 1 (0·2) | 7 (1·6) | 2 (0·4) | 8 (1·8) | 10 (2·2) |
| | 50– | 429 | 146 | 2 (0·5) | 7 (1·6) | 4 (0·9) | 14 (3·3) | 18 (4·2) |
| | 55– | 379 | 141 | 1 (0·3) | 5 (1·3) | 2 (0·5) | 11 (2·9) | 22 (5·8) |
| | 60–62 | 65 | 27 | — (—) | 2 (3·1) | 1 (1·5) | 2 (3·1) | 1 (1·5) |
| | Total .. | 2,873 | 796 | 6 (0·2) | 33 (1·1) | 10 (0·3) | 52 (1·8) | 66 (2·3) |

TABLE

MORTALITY IN 8 YEARS ACCORDING TO INITIAL ECG BY CAUSE OF

| ECG Group | Minnesota Code | Males | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | No. in Group | Sudden | | | Other Coronary | | | Non-Coronary | | | Total Deaths | | |
| | | | Obs. | Exp. | Risk | Obs. | Exp. | Risk | Obs. | Exp. | Risk | Obs. | Exp. | Risk |
| No reportable ECG items .. | $I_0$ | 1,539 | 25 | 32·78 | 0·8 | 21 | 24·97 | 0·8 | 68 | 79·87 | 0·9 | 116 | 138·53 | 0·8 |
| Q waves alone .. .. .. | $I_1$ | 5 | 2 | 0·20 | 10·0 | 0 | 0·15 | — | 0 | 0·40 | — | 2 | 0·78 | 2·6 |
| | $I_2$ | 16 | 1 | 0·33 | 3·0 | 1 | 0·36 | 2·8 | 0 | 1·09 | — | 2 | 1·81 | 1·1 |
| | $I_3$ | 4 | 0 | 0·04 | — | 0 | 0·01 | — | 0 | 0·08 | — | 0 | 0·13 | — |
| | $I_{123}$ | 25 | 3 | 0·57 | 5·3 | 1 | 0·52 | 1·9 | 0 | 1·57 | — | 4 | 2·27 | 1·5 |
| ST depression alone .. .. | $IV_{123}$ | 22 | 0 | 0·71 | — | 0 | 0·59 | — | 7 | 1·55 | 4·5 | 7 | 2·99 | 2·3 |
| T wave inversion alone .. | $V_{12}$ | 13 | 2 | 0·29 | 6·9 | 1 | 0·22 | 4·5 | 3 | 0·69 | 4·4 | 6 | 1·19 | 5·0 |
| Flat T waves alone .. .. | $V_3$ | 159 | 2 | 3·69 | 0·5 | 3 | 3·29 | 0·9 | 13 | 9·73 | 1·3 | 18 | 17·10 | 1·1 |
| Q waves and ST depression .. | $I_{123}+IV_{123}$ | 0 | — | — | — | — | — | — | — | — | — | — | — | — |
| Q waves and T wave inversion | $I_{123}+V_{12}$ | 10 | 2 | 0·41 | 4·9 | 4 | 0·35 | 11·4 | 1 | 0·94 | 1·1 | 6 | 1·68 | 4·2 |
| Q waves and Flat T waves .. | $I_{123}+V_3$ | 5 | 1 | 0·15 | 6·7 | 0 | 0·16 | — | 0 | 0·41 | — | 1 | 0·75 | 1·3 |
| ST depression and T wave inversion .. .. | $IV_{123}+V_{12}$ | 22 | 4 | 0·66 | 6·1 | 1 | 0·59 | 1·7 | 7 | 1·65 | 4·2 | 12 | 2·93 | 4·1 |
| ST depression and Flat T waves | $IV_{123}+V_3$ | 9 | 3 | 0·29 | 10·3 | 2 | 0·24 | 8·3 | 1 | 0·66 | 1·5 | 6 | 1·23 | 4·9 |
| Q waves and ST depression and T wave inversion .. .. | $I_{123}+IV_{123}+V_{12}$ | 7 | 3 | 0·24 | 12·5 | 0 | 0·29 | — | 1 | 0·77 | 1·3 | 4 | 1·31 | 3·1 |
| Q waves and ST depression and Flat T waves .. .. .. | $I_{123}+IV_{123}+V_3$ | 3 | 0 | 0·12 | — | 1 | 0·13 | 7·7 | 0 | 0·35 | — | 1 | 0·59 | 1·7 |
| Framingham Heart Programme Prevalence Cases (FHP) .. .. .. .. .. .. | | 54 | 10 | 1·83 | 5·5 | 8 | 1·72 | 4·7 | 5 | 4·62 | 1·1 | 23 | 8·31 | 2·8 |

and unexpected) which are considered probably due to coronary disease, other coronary deaths, and deaths not due to coronary disease are shown. The expected number of deaths from these causes has been calculated from the age/sex specific rates in the whole sample (Table VI, overleaf) by applying these rates to the age distribution of the Minnesota Code groups.

The four criteria—Q wave items, ST depression, T wave inversion, and T wave flattening—most relevant to coronary disease, have been considered both separately and in combination. The numbers are small particularly in women. In both sexes ECG abnormalities at the initial examination were associated with an increased risk of dying of coronary heart disease (sudden death and other coronary

IV

SEX IN FRAMINGHAM POPULATION (PERCENTAGES IN BRACKETS)

| ST Depression | | | T Wave Changes | | | Ventricular Conduction | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Inversion | | Flat T | | | | |
| IV$_1$ | IV$_2$ | IV$_3$ | V$_1$ | V$_2$ | V$_3$ | VII$_1$ | VII$_2$ | VII$_3$ | VII$_4$ |
| — (—) | 2 (0·5) | 1 (0·3) | — (—) | 1 (0·3) | 23 (5·9) | 1 (0·3) | 1 (0·3) | 6 (1·5) | 2 (0·5) |
| 1 (0·2) | 1 (0·2) | 2 (0·5) | — (—) | 9 (2·0) | 30 (6·8) | — (—) | — (—) | 8 (1·8) | 1 (0·2) |
| 4 (1·0) | 3 (0·7) | 1 (0·2) | — (—) | 5 (1·2) | 28 (6·7) | 1 (0·2) | 2 (0·5) | 10 (2·4) | 2 (0·5) |
| 1 (0·3) | 4 (1·1) | 4 (1·1) | — (—) | 6 (1·7) | 24 (6·7) | 2 (0·6) | 2 (0·6) | 6 (1·6) | — (—) |
| 6 (1·6) | 8 (2·1) | 5 (1·3) | 3 (0·8) | 12 (3·2) | 26 (7·0) | 1 (0·3) | 1 (0·3) | 8 (2·1) | 4 (1·1) |
| 6 (2·2) | 4 (1·4) | 5 (1·8) | 2 (0·7) | 12 (4·3) | 28 (10·1) | 2 (0·7) | 2 (0·7) | 3 (1·1) | 1 (0·4) |
| 1 (1·3) | — (—) | 4 (5·3) | — (—) | 2 (2·7) | 17 (22·7) | — (—) | 2 (2·7) | — (—) | — (—) |
| 19 (0·8) | 22 (0·9) | 22 (0·9) | 5 (0·2) | 47 (2·0) | 176 (7·5) | 7 (0·3) | 10 (0·4) | 41 (1·8) | 10 (0·4) |
| 2 (0·4) | 3 (0·7) | 2 (0·4) | — (—) | 4 (0·9) | 22 (4·8) | 1 (0·2) | 1 (0·2) | 2 (0·4) | 1 (0·2) |
| — (—) | 2 (0·3) | 2 (0·3) | — (—) | 6 (1·0) | 36 (6·2) | 1 (0·2) | — (—) | 5 (0·9) | — (—) |
| — (—) | 11 (2·1) | 2 (0·4) | — (—) | 9 (1·8) | 42 (8·2) | 1 (0·2) | — (—) | — (—) | — (—) |
| — (—) | 9 (2·0) | 6 (1·3) | — (—) | 7 (1·6) | 43 (9·6) | 2 (0·4) | 1 (0·2) | 2 (0·4) | 1 (0·2) |
| 4 (0·9) | 13 (3·0) | 7 (1·6) | — (—) | 17 (4·0) | 59 (13·8) | 4 (0·9) | 2 (0·5) | 4 (0·9) | — (—) |
| 4 (1·1) | 18 (4·7) | 8 (2·1) | 2 (0·5) | 11 (2·9) | 46 (12·1) | 3 (0·8) | 2 (0·5) | 9 (2·4) | 1 (0·3) |
| — (—) | 4 (6·2) | — (—) | 1 (1·5) | 1 (1·5) | 8 (12·3) | 1 (1·5) | — (—) | 1 (1·5) | — (—) |
| 10 (0·3) | 60 (2·1) | 27 (0·9) | 3 (0·1) | 55 (1·9) | 256 (8·9) | 13 (0·5) | 6 (0·2) | 23 (0·8) | 3 (0·1) |

V

DEATH AND SEX (PERSONS AGED 30–62 AT FIRST EXAMINATION)

| Females | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. in Group | Sudden | | | Other Coronary | | | Non-Coronary | | | Total Deaths | | |
| | Obs. | Exp. | Risk | Obs. | Exp. | Risk | Obs. | Exp. | Risk | Obs. | Exp. | Risk |
| 2,077 | 4 | 6·71 | 0·6 | 8 | 9·75 | 0·8 | 66 | 74·82 | 0·9 | 79* | 91·97 | 0·9 |
| 4 | 0 | 0·02 | — | 0 | 0·03 | — | 0 | 0·14 | — | 0 | 0·19 | — |
| 23 | 0 | 0·11 | — | 0 | 0·16 | — | 2 | 1·00 | 2·0 | 2 | 1·28 | 1·6 |
| 8 | 0 | 0·06 | — | 1 | 0·10 | 10·0 | 0 | 0·44 | — | 1 | 0·60 | 1·7 |
| 35 | 0 | 0·19 | — | 1 | 0·29 | 3·5 | 2 | 1·58 | 1·3 | 3 | 2·07 | 1·4 |
| 43 | 0 | 0·20 | — | 0 | 0·35 | — | 5 | 1·92 | 2·6 | 5 | 2·49 | 2·0 |
| 26 | 0 | 0·08 | — | 1 | 0·09 | 11·1 | 1 | 0·97 | 1·0 | 2 | 1·16 | 1·7 |
| 228 | 2 | 0·97 | 2·1 | 3 | 1·40 | 2·1 | 11 | 9·80 | 1·1 | 16 | 12·29 | 1·3 |
| 2 | 0 | 0·01 | — | 0 | 0 | — | 0 | 0·11 | — | 0 | 0·12 | — |
| 1 | 0 | 0·01 | — | 0 | 0·02 | — | 1 | 0·06 | 16·7 | 1 | 0·09 | 11·1 |
| 7 | 0 | 0·02 | — | 0 | 0·01 | — | 0 | 0·34 | — | 0 | 0·38 | — |
| 27 | 0 | 0·16 | — | 1 | 0·27 | 3·7 | 6 | 1·52 | 3·9 | 7 | 1·98 | 3·5 |
| 21 | 1 | 0·13 | 7·7 | 0 | 0·26 | — | 4 | 1·14 | 3·5 | 5 | 1·55 | 3·2 |
| 4 | 0 | 0·03 | — | 0 | 0·05 | — | 0 | 0·23 | — | 0 | 0·31 | — |
| 0 | — | — | — | — | — | — | — | — | — | — | — | — |
| 27 | 1 | 0·17 | 5·9 | 2 | 0·29 | 6·9 | 1 | 1·48 | 0·7 | 4 | 1·96 | 2·0 |

* 1 NR cause

TABLE VI

NUMBER OF DEATHS AND RATES PER CENT. FOR THE 8-YEAR PERIOD IN THE FRAMINGHAM POPULATION, BY AGE AND SEX (PERCENTAGES IN BRACKETS)

| Sex | Age Group (yrs) | No. in Population | No. of Deaths | | | |
|---|---|---|---|---|---|---|
| | | | Sudden | Other Coronary | Non-Coronary | Total |
| Male | 29–34 | 391 | 1 (0·3) | 1 (0·3) | 8 (2·0) | 10 (2·6) |
| | 35–39 | 441 | 4 (0·9) | 1 (0·2) | 8 (1·8) | 13 (2·9) |
| | 40–44 | 421 | 6 (1·4) | 1 (0·2) | 12 (2·9) | 19 (4·5) |
| | 45–49 | 358 | 10 (2·8) | 7 (2·0) | 21 (5·9) | 38 (10·6) |
| | 50–54 | 373 | 18 (4·8) | 12 (3·2) | 31 (8·3) | 61 (16·3) |
| | 55–59 | 277 | 9 (3·2) | 14 (5·1) | 37 (13·4) | 60 (21·7) |
| | 60–62 | 75 | 3 (4·0) | 4 (5·3) | 9 (12·0) | 18* (24·0) |
| | Total .. .. | 2,336 | 51 | 40 | 126 | 219 |
| Female | 29–34 | 454 | 0 (—) | 2 (0·4) | 9 (2·0) | 11 (2·4) |
| | 35–39 | 583 | 0 (—) | 0 (—) | 11 (1·9) | 11 (1·9) |
| | 40–44 | 513 | 1 (0·2) | 0 (—) | 13 (2·5) | 14 (2·7) |
| | 45–49 | 450 | 3 (0·7) | 1 (0·2) | 18 (4·0) | 22 (4·9) |
| | 50–54 | 429 | 2 (0·5) | 1 (0·2) | 28 (6·5) | 32† (7·5) |
| | 55–59 | 379 | 3 (0·8) | 8 (2·1) | 24 (6·3) | 35 (9·2) |
| | 60–62 | 65 | 1 (1·5) | 3 (4·6) | 5 (7·7) | 9 (13·8) |
| | Total .. .. | 2,873 | 10 | 15 | 108 | 134 |

* 2 Cause not known. † 1 Cause not known.

deaths). Isolated Q waves appeared to be associated with a more than three-fold excess risk in men and the larger the Q wave the higher the risk. In both sexes, isolated T wave inversion seemed to carry an appreciably increased risk. Women with ECGs showing isolated flat T waves had about twice the average risk, but in the men the risk with this abnormality was less than average. ST depression combined with T wave changes carried an increased risk in both sexes. In men this combination agreed closely with the risk noted for subjects diagnosed as having coronary disease after full examination (prevalence cases). A similar excess risk was noted when these ST-T changes occurred in association with Q waves. This suggests that this combination of abnormalities probably indicates preclinical or unrecognized coronary heart disease. A summary of the main findings for men and women combined is shown in Fig. 1.

Some excess risk of non-coronary deaths was associated with these ECG abnormalities. It is possible that some of these deaths were partly cardiovascular in aetiology, since the risk of cerebrovascular accidents has been shown to be excessive in subjects with ECG abnormalities (Kannel and others, 1961).

*Classification of the ECGs of the Prevalence Cases*

81 persons, 54 men and 27 women, were diagnosed at the first Framingham examination as

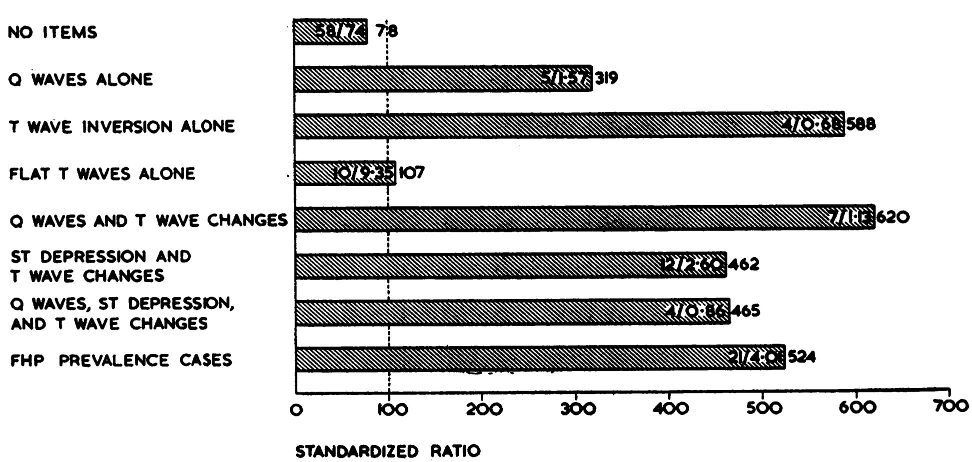


FIG. 1.—Risk of coronary heart disease death in 8 years according to initial electrocardiogram (8-year follow-up, Framingham Heart Project, men and women aged 30–62).

having coronary disease. The classification of their ECGs according to the Minnesota Code is of interest for two reasons. First, it indicates the code items which permit a fairly confident diagnosis of coronary disease to be made; secondly, it reveals the proportion of cases in which the ECG provides little or no evidence of the disease. The prevalence of coronary disease as determined at the first Framingham examination according to the Minnesota classification of the initial ECG is shown in Table VII.

0·8 per cent. of the men and 0·2 per cent. of the women who had no reportable code items had been diagnosed as prevalence cases. On the other hand, over half of those with large Q wave items alone and nearly a quarter of those with intermediate Q wave items alone, and all eleven persons with Q wave items combined with T wave inversion had been diagnosed. Rather surprisingly there were three men and four women who had ST depression as well as Q wave items combined with T wave inversion who were not diagnosed.

### *8-Year Morbidity according to Initial ECG*

The risk of developing coronary disease according to initial ECG is shown in Table VIII (overleaf). The prevalence cases have been subtracted from the initial numbers in the group to obtain the population at risk.

An increased risk of development of the disease in men was observed in those whose ECGs showed large or intermediate Q waves, T wave inversion, and also to some extent flat T waves, particularly when these occurred with ST depression. In women, an increased risk was observed in those with ST depression with flat or inverted T waves with or without associated Q waves, but the numbers are too small for firm conclusions. Fig. 2 (overleaf) again summarizes the main findings for men and women combined.

The increased risk associated with ST and T wave changes is consistent with previous findings at Framingham, where "left ventricular hypertrophy" and "non-specific ST-T abnormalities" were shown to carry about a two-fold excess risk of developing coronary heart disease.

### International Comparison

ECGs from two other areas have been classified by the same reader in the same way as the population of Framingham. The first was of a random sample of 537 miners and ex-miners and non-miners aged 35–64 from the Rhondda Fach, Glamorgan, in South Wales (Higgins and others, 1963). The second was of a random sample of men and women aged 35–64 living in Jamaica which was studied by Dr W. E. Miall (Miall and others, 1965).

TABLE VII

PREVALENCE OF CORONARY DISEASE ACCORDING TO INITIAL ECG, BY SEX (PERSONS AGED 30–62 AT FIRST EXAMINATION)

| ECG Group | Code | Males | | | Females | | |
|---|---|---|---|---|---|---|---|
| | | No. in Group | Coronary Disease | | No. in Group | Coronary Disease | |
| | | | No. | Rate Per cent. | | No. | Rate Per cent. |
| No reportable ECG items | $I_0$ | 1,539 | 13 | 0·8 | 2,077 | 5 | 0·2 |
| Q waves alone | $I_1$ | 5 | 3 | 60·0 | 4 | 2 | 50·0 |
| | $I_2$ | 16 | 4 | 25·0 | 23 | 4 | 17·4 |
| | $I_3$ | 4 | 0 | — | 8 | 2 | 25·0 |
| | $I_{123}$ | 25 | 7 | 28·0 | 35 | 8 | 22·9 |
| ST depression alone | $IV_{123}$ | 22 | 0 | — | 43 | 0 | — |
| T wave inversion alone | $V_{12}$ | 13 | 2 | 15·4 | 26 | 0 | — |
| Flat T waves alone | $V_3$ | 159 | 5 | 3·1 | 228 | 6 | 2·6 |
| Q waves and T wave inversion | $I_{123}+V_{12}$ | 10 | 10 | 100·0 | 1 | 1 | 100·0 |
| Q waves and Flat T waves | $I_{123}+V_3$ | 5 | 2 | 40·0 | 7 | 2 | 28·6 |
| ST depression and T wave inversion | $IV_{123}+V_{12}$ | 22 | 2 | 9·1 | 27 | 1 | 3·7 |
| ST depression and Flat T waves | $IV_{123}+V_3$ | 9 | 1 | 11·1 | 21 | 1 | 4·8 |
| Q waves and ST depression and T wave inversion | $IV_{123}+IV_{123}+V_{12}$ | 7 | 4 | 57·1 | 4 | 0 | — |
| Q waves and ST depression and Flat T waves | $I_{123}+IV_{123}+V_3$ | 3 | 1 | 33·3 | 0 | — | — |
| Q waves *or* ST depression *or* T wave changes | $I_{123}$ *or* $IV_{123}$ *or* $V_{123}$ | 275 | 34 | 12·4 | 394 | 19 | 4·8 |

TABLE VIII

RISK OF CORONARY DISEASE IN 8 YEARS ACCORDING TO INITIAL ECG, BY SEX (PERSONS AGED 30–62 AT FIRST EXAMINATION)

| ECG Group | Minnesota Code | Males | | | | Females | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | No. at Risk | Cases Observed | Cases Expected | Risk | No. at Risk | Cases Observed | Cases Expected | Risk |
| No reportable ECG items .. .. | $I_0$ | 1,526 | 99 | 107·4 | 0·9 | 2,072 | 49 | 52·9 | 0·9 |
| Q waves alone .. .. .. | $I_1$ | 2 | 1 | 0·15 | 6·7 | 2 | 0 | — | — |
| | $I_2$ | 12 | 4 | 1·27 | 3·2 | 19 | 0 | — | — |
| | $I_3$ | 4 | 0 | 0·15 | — | 6 | 0 | — | — |
| | $I_{123}$ | 18 | 5 | 1·57 | 3·2 | 27 | 0 | 0·91 | — |
| ST depression alone .. .. .. | $IV_{123}$ | 22 | 2 | 2·26 | 0·9 | 43 | 2 | 1·82 | 1·1 |
| T wave inversion alone .. .. | $V_{12}$ | 11 | 4 | 0·89 | 4·5 | 26 | 1 | 0·68 | 1·5 |
| Flat T waves alone .. .. .. | $V_3$ | 154 | 19 | 13·09 | 1·5 | 222 | 7 | 7·75 | 0·9 |
| Q waves and T wave inversion .. | $I_{123}+V_{12}$ | 0 | — | — | — | 0 | — | — | — |
| Q waves and Flat T waves .. .. | $I_{123}+V_3$ | 3 | 0 | 0·43 | — | 5 | 0 | 0·12 | — |
| ST depression and T wave inversion .. | $IV_{123}+V_{.2}$ | 20 | 3 | 1·91 | 1·6 | 26 | 3 | 1·33 | 2·3 |
| ST depression and Flat T waves .. | $IV_{123}+V_3$ | 8 | 4 | 0·85 | 4·2 | 20 | 2 | 1·17 | 1·7 |
| Q waves and ST depression and T wave inversion .. .. .. | $I_{123}+IV_{123}+V_{12}$ | 3 | 1 | 0·39 | 2·6 | 4 | 1 | 0·26 | 3·9 |
| Q waves and ST depression and Flat T waves .. .. .. | $I_{123}+IV_{123}+V_3$ | 2 | 2 | 0·33 | 6·1 | 0 | — | — | — |
| Q waves *or* ST depression *or* T wave changes .. .. .. | $I_{123}$ *or* $IV_{123}$ *or* $V_{123}$ | 241 | 40 | 21·72 | 1·8 | 375 | 16 | 14·11 | 1·1 |

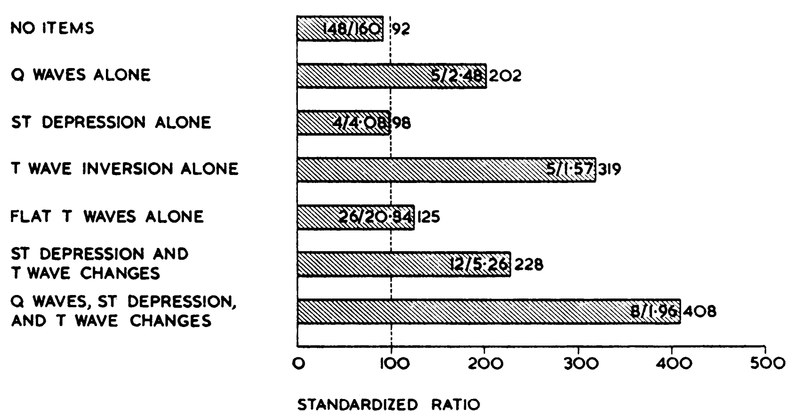


FIG. 2.—Risk of coronary heart disease incident in 8 years according to initial electrocardiogram (8-year follow-up, Framingham Heart Project, men and women aged 30–62).

Table IX (opposite) shows the comparison with the Framingham results. The Welsh and Jamaican groups are slightly older (about 5 years) than the Framingham sample and some allowance must be made for this in the comparison.

In the men, the frequency of Q and QS items was highest in Jamaica and lowest in the Rhonnda, with Framingham intermediate. Tall R waves ranked the areas in the same order. ST depression and T wave inversion, on the other hand, appeared to be more frequent in the Rhonnda than in either Framingham or Jamaica, while flat T waves were less frequent in the Rhondda than elsewhere. All T wave changes ranked the areas in the same order as the Q and QS items.

Women were not studied by ECGs in the Rhondda sample, so that we can compare only Framingham and Jamaica. In the women, as in the men, Q wave

TABLE IX

COMPARISON OF FREQUENCY OF MINNESOTA CODE ITEMS IN THREE POPULATIONS, BY SEX (PERCENTAGES IN BRACKETS) (ALL ECGs CLASSIFIED BY THE SAME PERSON)

| Abnormality | Minnesota Code | Males | | | Females | |
|---|---|---|---|---|---|---|
| | | Framingham (30–62) (2,336 men) | Rhondda Fach (35–64) (537 men) | Jamaica (35–64) (269 men) | Framingham (30–62) (2,873 women) | Jamaica (35–64) (279 women) |
| Q waves .. .. .. | $I_1$ | 14 (0·6) | 1 (0·2) | 3 (1·1) | 6 (0·2) | 2 (0·7) |
| | $I_2$ | 28 (1·2) | 6 (1·1) | 8 (3·0) | 33 (1·1) | 5 (1·8) |
| | Total .. | 42 (1·8) | 7 (1·3) | 11 (4·1) | 39 (1·4) | 7 (2·5) |
| Tall R waves .. .. | $III_1$ | 182 (7·8) | 25 (4·7) | 52 (19·3) | 66 (2·3) | 28 (10·0) |
| ST Depression .. .. | $IV_1$ | 19 (0·8) | 13 (2·4) | 1 (0·4) | 10 (0·3) | 4 (1·4) |
| | $IV_2$ | 22 (0·9) | 12 (2·2) | 5 (1·9) | 60 (2·1) | 13 (4·7) |
| | $IV_3$ | 22 (0·9) | 9 (1·7) | 2 (0·7) | 27 (0·9) | 3 (1·1) |
| | Total .. | 63 (2·6) | 34 (6·3) | 8 (3·0) | 97 (3·4) | 20 (7·2) |
| T wave inversion .. | $V_1$ | 5 (0·2) | 3 (0·6) | 1 (0·4) | 3 (0·1) | 2 (0·7) |
| | $V_2$ | 47 (2·0) | 19 (3·5) | 6 (2·2) | 55 (1·9) | 8 (2·9) |
| | Total .. | 52 (2·2) | 22 (4·1) | 7 (2·6) | 58 (2·0) | 10 (3·6) |
| Flat T waves .. .. | $V_3$ | 176 (7·5) | 14 (2·6) | 23 (8·6) | 256 (8·9) | 32 (11·5) |
| All T wave changes .. | $V_{1-3}$ | 228 (9·8) | 36 (6·7) | 20 (11·2) | 314 (10·9) | 42 (15·1) |
| A–V conduction defects .. | $VI_{1-4}$ | 19 (0·7) | 17 (3·2) | 9 (3·3) | 22 (0·8) | 2 (0·7) |
| I–V conduction defects .. | $VII_{1-4}$ | 68 (2·9) | 29 (5·4) | 8 (3·0) | 45 (1·6) | 2 (0·7) |
| Arrhythmias .. .. | $VIII_{1-6}$ | 43 (1·9) | 8 (1·5) | N/A | 46 (1·6) | N/A |

items and tall R waves were commoner in Jamaica. But in the women, unlike the men, so also were ST depression, T wave inversion, and flat T waves.

When the sexes are compared within one area, a slightly higher frequency of Q wave changes (mainly large Q waves) was recorded in the men. Tall R waves were also commoner in men in both areas. ST depression was commoner in women in both areas and T wave inversion slightly commoner in women in Jamaica, but much the same in women as in men at Framingham. The comparison suggests that there need be no close correlation between Q wave items and ST-T wave items in any community.

In attempting the grouping of ECG items, persons with ECG abnormalities were classified as having probable or possible coronary heart disease using the following criteria:

(1) *Probable Coronary Diseases.*—Q waves with T wave inversion (items $I_1$, $I_2$, or $I_3$ with $V_1$ or $V_2$); large Q waves alone (item $I_1$).

(2) *Possible Coronary Disease.*—Intermediate Q waves alone (item $I_2$), T wave inversion alone (items $V_1$ or $V_2$), ST depression and T wave changes together (items $IV_1$, $IV_2$ or $IV_3$ with $V_1$, $V_2$, or $V_3$).

Isolated ST depression or flat T waves were ignored; Table X shows that such a classification adds little.

TABLE X

COMPARISON OF JAMAICAN AND FRAMINGHAM POPULATIONS BY SEX AND AGE, ON THE BASIS OF THE CRITERIA SUGGESTED FOR PROBABLE AND POSSIBLE "CORONARY DISEASE". NUMBER OF CASES AND PROPORTION PER CENT

| Sex | Diagnostic Group | Jamaica | | | | Framingham |
|---|---|---|---|---|---|---|
| | | 35–44 yrs | 45–54 yrs | 55–64 yrs | All Ages | 30–62 yrs |
| Male | Total Men | 90 | 90 | 89 | 269 | 2,336 |
| | Probable .. | 0 (—) | 2 (2·2) | 3 (3·3) | 5 (1·9) | 15 (0·6) |
| | Possible .. .. | 4 (4·4) | 2 (2·2) | 5 (5·6) | 11 (4·1) | 70 (3·0) |
| | Total .. .. | 4 (4·4) | 4 (4·4) | 8 (8·9) | 16 (6·0) | 85 (3·6) |
| Female | Total Women .. | 96 | 90 | 93 | 279 | 2,873 |
| | Probable .. | 0 (—) | 1 (1·1) | 1 (1·1) | 2 (0·7) | 5 (0·2) |
| | Possible .. .. | 3 (3·1) | 4 (4·4) | 5 (5·4) | 12 (4·3) | 101 (3·5) |
| | Total .. .. | 3 (3·1) | 5 (5·5) | 6 (6·5) | 14 (5·0) | 106 (3·7) |

There were too few cases of probable coronary disease. In both areas the possible cases were rather commoner in women than in men. The probable changes are, however, commoner in men and show some age trend in both sexes. It appears, however, that such changes are commoner in Jamaica than in Framingham.

## Discussion

The object of classifying ECGs in a standardized manner is to make valid comparisons of the frequencies of the items recorded, particularly of those which correlate highly with the presence or future development of coronary disease, between different population groups. Identification of the most significant items can be considered valid only for the population of Framingham though it is likely that they could safely be applied to other similar areas of the eastern USA. General extension to European countries should however be made with great caution, at least until studies there have supported the findings in Framingham. Comparisons between countries in other continents, Africa and South America for example, should be even more cautiously made. In spite of this reservation about the implication of code items in different geographical locations, their frequency may certainly be compared in different samples provided they are not attributed to coronary disease.

Comparison of the frequency of the code items in various groups was given in the paper by Blackburn and others (1960), Table XI. A high frequency of Q and QS items, ST depression, and T wave changes was found in patients with old anterior myocardial infarction compared with a group of normal railroad employees. These items, and possibly also ventricular conduction defects, all appeared to be useful indicators of coronary disease. Similar changes were, however, seen in the group of patients diagnosed as having emphysema, and consequently some cases of emphysema might be misdiagnosed as coronary disease if only these ECG items are considered. Old posterior infarction was not considered and might present greater difficulty since the problem of differentiating normal from abnormal Q waves in lead III is well known.

Table XI also gives a comparison between three groups of men more representative of the general community; two of these were of communities in Yugoslavia, the third was of a sample of railroad employees (Taylor, Klepetar, Keys, Parlin, Blackburn, and Puchner, 1962). A higher frequency of ST and T wave items and high R waves was recorded in Slavonia than in Dalmatia, but the frequency of all Q and QS items appeared to be the same. These Q and QS items were, however, only half as common in Yugoslavia as in the United States railroad men, a finding which is consistent with mortality statistics for coronary disease in the two countries. ST and T wave changes occurred with about equal frequency in the Yugoslav and US groups, suggesting that there need be no close correlation between abnormal Q waves and ST and T wave items.

The high frequency of ECG changes in Jamaica is interesting in view of the rarity of coronary disease there (Cruickshank, 1964). These changes may be due to myocardial lesions caused by some condition other than disease of the coronary arteries. Aortic dilatation and positive serological reactions (Stuart, Miall, Tulloch, and Christian, 1962) are relevant to this problem, as well as possible nutritional and infective lesions in the myocardium.

A striking finding both in Framingham and in Jamaica has been the similar frequency of most

Table XI

FREQUENCY OF MINNESOTA CODE ITEMS IN SIX POPULATION SAMPLES STUDIED BY BLACKBURN AND OTHERS (1960) (PERCENTAGES IN BRACKETS)

| Abnormality | Minnesota Code | Screened Normal Railroad Employees (461) | Old Anterior Myocardial Infarction Confirmed Autopsy Cases (100) | Pulmonary Emphysema No Coronary Heart Disease at Autopsy (60) | Men Aged 40–59 in Yugoslavia: Dalmatia (699) | Men Aged 40–59 in Yugoslavia: Slavonia (694) | Men Aged 40–59 from U.S. Railroad Switchmen, Clerks, Executives (1,267) |
|---|---|---|---|---|---|---|---|
| Q wave and QS Items | $I_{1-3}$ | 6 (1·3) | 91 (91·0) | 8 (13·3) | 13 (1·9) | 13 (1·9) | 50 (3·9) |
| High R waves .. .. | $III_{1-2}$ | 8 (1·7) | 1 (1·0) | 6 (10·0) | 21 (3·1) | 78 (11·2) | 32 (2·5) |
| ST Depression .. | $IV_{1-3}$ | 2 (0·4) | 26 (26·0) | 12 (20·0) | 11 (1·6) | 20 (2·9) | 33 (2·6) |
| T wave items .. | $V_{1-3}$ | 8 (1·7) | 91 (91·0) | 17 (28·3) | 9 (1·3) | 41 (5·9) | 56 (4·4) |
| A–V Conduction .. | $VI_{1-4}$ | 0 (—) | 1 (1·0) | 0 (—) | 3 (0·4) | 3 (0·4) | 9 (0·7) |
| Ventricular Conduction | $VII_{1-4}$ | 3 (0·6) | 10 (10·0) | 16 (26·7) | 19 (2·8) | 10 (1·4) | 41 (3·2) |
| Arrhythmias .. .. | $VIII_{2-6}$ | 8 (1·7) | 9 (9·0) | 7 (11·7) | 11 (1·6) | 12 (1·7) | 4 (0·3) |

abnormal Q waves, ST, and T wave items in men and women. Only large Q waves appeared to be commoner in men. At least in Framingham the similar frequency of these items is at variance with the frequency of coronary heart disease. This raises several questions:

Do the changes in the two sexes indicate a similar frequency of pathological change in the myocardium? If so, why are women less affected by these changes than men? Is the similar frequency of changes in the two sexes to some extent the result of grouping items?

Women have been much less studied than men because of their lower frequency of coronary disease. Their rather similar frequency of ECG changes suggests, however, that they might be more often included in such studies and that the findings on them might throw considerable light on the implications of these findings.

The frequency of ECGs showing changes which can be confidently diagnosed as indicating coronary disease in a prevalence survey is small. The numbers in the Rhondda and Jamaican populations on which the international comparison described in this paper has been based are certainly too few for any confident conclusions about the relative frequencies of ECG items in the three areas, let alone any attribution of these items to coronary disease. The comparison suggested that 750–1,000 men or women in the 40–59 age range should provide a sufficient number of the more definite changes for valid comparisons between different areas. This number is, in fact, that advocated and used by Keys and his colleagues in international epidemiological studies. Theoretical considerations led Rose (see W.H.O., 1963) to suggest 500–600 men in this age range as an sitable number for international comparisons.


## Summary

The 5,219 electrocardiograms taken at the first examination of the sample of men and women participating in the Framingham Heart Project have been classified according to the Minnesota code. All the readings were made by one reader. The validity of abnormal Q waves, ST depression, and T wave changes in the code was assessed by relating the relevant item to the diagnosis of coronary disease established at the initial examination, after full investigation, and to the subsequent development of and mortality from the disease in the 8-year follow-up period.

Persons with no reportable ECG code items had a lower than average risk of developing or dying from coronary disease. Those with isolated Q waves had approximately three times the average risk of dying of coronary disease. Those in whom the change was not considered diagnostic at the first examination had about twice the average risk of developing the disease. The larger the Q waves the greater the risk. Isolated T waves carried a 5-fold increased risk of death and a 3-fold increased risk of an incident of coronary heart disease. Isolated ST depression and flat T waves did not increase the risks materially. Various combinations of the items increased the risk of death to about four to six times the average and the risk of an incident about two to four times.

440 ECGs were read on two occasions to measure intra-observer variation. While the classification of tracings into normal and abnormal was fairly good, the coding varied in a considerable proportion on the two occasions. Reproducibility was good for Q wave items, but less so for ST and T wave changes. Measurement of the various waves indicated that some of the variation was due to misclassification, which should be correctable.

Two other communities in which ECGs have been included in random sample surveys are compared with the findings in Framingham. One of these was a rural community in Jamaica, where a high frequency of abnormalities was noted in both men and women. The implications are discussed.


When this work was carried out Dr I. T. T. Higgins was Assistant Director of the Medical Research Council's Epidemiological Research Unit, 4 Richmond Road, Cardiff, Glamorgan. It is a pleasure to acknowledge the generosity of the Council and the helpful advice of Prof. A. L. Cochrane, Director of the Unit. We should also like to thank Dr. Henry Blackburn for instruction in the code and our colleagues in Framingham and Cardiff for their invaluable assistance.

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# APPENDIX

## Extract of Minnesota Code of Blackburn, Keys, Simonson, Rautaharju, and Punsar (1960)

### Definitions

(1) Baseline reference levels and intervals are read according to recommendations of the American Heart Association Criteria Committee:

P amplitude from T or U-P interval.

QRS amplitudes from P-R interval at onset of QRS.

T amplitude from T or U-P when possible, otherwise the level of trace at the beginning of QRS.

P-R interval is the longest in any limb lead.

QRS duration is the longest in any limb lead.

(2) A Q wave must be 1 mm. deep followed by an R wave of 1 mm.

(3) An initial R wave must be a definite departure above the P-R baseline, not simply a lift or rising slope of the P-R baseline.

### Reading of Intervals and Amplitudes

Beat-to-beat variability of interval measurements is troublesome. In practice it is helpful to require that a *majority* of beats recorded for the particular lead meet the critical duration criterion. Longer and 50 mm. per second strips aid materially in this respect and occasionally measurements from the post-exercise record may elucidate a questionable item. As a rule, however, all Q and QS items, R amplitudes, etc., are measured in the resting electrocardiogram.

Q and R waves under 1 mm. amplitude are read with poor reliability in direct-recorded tracings at 25 mm. per second paper speed. The lack of adequate data on large Q/R ratio or wide Q duration in overall low amplitude QRS complexes has led us to the arbitrary but practicable minimum criteria for Q and R amplitudes spelled out in the classification system.

Mean heart rate from leads I and $V_6$ of the resting record are employed for the criteria of tachycardia and bradycardia.

The criteria for amplitude of decreasing R waves from $V_1$ to $V_4$ is derived from our own studies in infarct and normal groups. Others have reported the interesting differences between observers in labelling of QS complexes or absent initial R waves. A full 1-mm. R wave is not necessary in the calling of an *initial* R wave, but a distinct sharp R deflection rising above the P-R baseline is required, not simply an ascending slope or terminal lift in the P-R segment.

The criteria for S-T depression give fair reliability between readers by considering these principles:

(1) S-T depression is placed in a questionable category or not tabulated when found in less than a majority of beats of the lead, when the baseline is swinging widely or sloping up or down, and when the S-T segment describes an arc with no clear junction with QRS.

(2) The junction (J) is taken at the end of QRS activity rather than at arbitrary points in the mid-arc or from the point of transition from very rapid to less rapid potential changes.

(3) S-T depression is read from the P-R segment baseline at the beginning of QRS.

(4) The post-exercise S-T depression criteria refer to an absolute value and not to a change relative to the resting level.

### The Classification

Findings are reported only when they appear in leads designated on the right-hand side of the classification below. "I, II, $V_2$–$V_6$" means *any* of leads I, II, $V_{2, 3, 4, 5,}$ or $_6$. "$V_1$ through $V_4$" means *all* of leads $V_1$ through $V_4$. A positive finding in *any* of the designated leads is reportable *unless* otherwise stipulated. Within each major category (Roman numeral) only the most significant deviation is reported (generally the lowest Arabic numeral). A finding that meets a criterion only in a single complex and therefore might be an artefact or expression of beat-to-beat variation is not reported as positive. Amplitudes refer to a calibration of 1 cm. = 1 mV.

CODE FOR RESTING ELECTROCARDIOGRAMS

| Col. | Punch | Category | Leads |
|---|---|---|---|
| O | 0 | Blank—no electrocardiogram available | |
| I | 0 | No herein reportable electrocardiographic items | |
| Q AND QS PATTERNS (Q must be 1 mm. or more with associated R of 1 mm. or more) | 1 | Class I. Any of (*a*) to (*g*)<br>(*a*) Q/R=1/3 or more *and* Q duration=0·03 sec. or more . . . . . .<br>(*b*) Q duration=0·04 sec. or more . .<br>(*c*) Q duration=0·04 sec. or more *and* R amplitude 3 mm. or more . . . .<br>(*d*) Q duration=0·05 sec. or more *and* a Q wave present in $aV_F$ . . . . . .<br>(*e*) Q duration=0·05 sec. or more . .<br>(*f*) QS pattern when R wave is present in adjacent precordial leads to the right . .<br>(*g*) QS pattern . . . . . . . . | <br><br>I, II, $V_2$-$V_6$<br>I, II, $V_1$-$V_6$<br><br>$aV_L$<br><br>III<br>$aV_F$<br><br>$V_2$-$V_6$<br>$V_1$ through $V_4$<br>$V_1$ through $V_5$<br>$V_1$ through $V_6$ |
| | 2 | Class II. Any of (*a*) to (*i*)<br>(*a*) Q/R=1/5 to 1/3 and Q duration=0·03 sec. or more . . . . . .<br>(*b*) Q duration=0·03 to 0·04 sec. . .<br>(*c*) Q duration=0·03 to 0·04 sec. and R amplitude 3 mm. or more . . . .<br>(*d*) Q duration=0·04 to 0·05 sec. and a Q wave present in $aV_F$ . . . .<br>(*e*) Q duration=0·04 to 0·05 sec. . .<br>(*f*) Q amplitudes=5 mm. or more . .<br>(*g*) QS pattern and absence of code $VII_1$<br>(*h*) Decreasing absolute R amplitude *and* smallest R=2 mm. or less *and* absence of code $III_2$ or $VII_{2,3}$ . . . . . .<br>(*i*) Q duration=0·04 sec. or more or a QS pattern . . . . . . . . . . | <br><br>I, II, $V_2$-$V_6$<br>I, II, $V_2$-$V_6$<br><br>$aV_L$<br><br>III<br>$aV_F$<br>III, $aV_F$<br>$V_1$ through $V_3$<br><br><br>$V_1$ through $V_3$, $V_4$<br><br>(Ancillary leads, see text) |
| | 3 | Class III. Any of (*a*) to (*c*) . . . .<br>(*a*) Q/R=1/3 or more *and* Q duration less than 0·03 sec. . . . . . . . .<br>(*b*) QS pattern *and* absence of code $VII_1$ or $III_1$ . . . . . . . . . .<br>(*c*) Q/R=1/5 to 1/3 *and* Q duration less than 0·03 sec. . . . . . . . . | <br><br>I, II, $V_2$-$V_6$<br><br>$V_1$ and $V_2$<br><br>I, II, $V_2$-$V_6$ |
| II<br><br>QRS AXIS DEVIATION | 1 | *Left*<br>QRS axis=−30° or greater . . . . | <br>I, II and III |
| | 2 | *Right*<br>QRS axis=+120° or greater . . . .<br>(The algebraic sum of major positive and major negative waves must be negative in I, positive in III, and in I must be one half or more of that in III) | <br>I, II and III |

*Continued overleaf*

CODE FOR RESTING ELECTROCARDIOGRAMS—*Continued*

| Col. | Punch | Category | Leads |
|---|---|---|---|
| III<br>HIGH AMPLITUDE R WAVES | 1 | *Left*<br>R more than 26 mm. .. .. ..<br>R more than 20 mm. .. .. ..<br>R more than 12 mm. .. .. .. | <br>$V_5$, $V_6$<br>I, II, III, $aV_F$<br>$aV_L$ |
| | 2 | *Right*<br>QRS duration less than 0·12 sec. *and* R amplitude=5 mm. or more *and* R/S Ratio=1·0 or more *and* QRS transition zone or decreasing R/S to left of $V_1$ (Includes incomplete RBBB which meets above criteria) .. .. .. | $V_1$ |
| IV<br>S-T JUNCTION AND SEGMENT (Measured from preceding P-R interval at onset of QRS) | 1 | *Depression*<br>S-T-J depression 1 mm. or more .. | I, II, $aV_L$, $aV_F$, $V_1$-$V_6$ |
| | 2 | S-T-J depression 0·5–0·9 mm. and S-T segment horizontal or downward sloping .. .. .. .. .. | I, II, $aV_L$, $aV_F$, $V_1$-$V_6$ |
| | 3 | No S-T-J depression as much as 0·5 mm. but S-T segment sloping down and reaching 0·5 mm. or more below P-R baseline .. .. .. .. .. | I, II, $aV_L$, $aV_F$, $V_1$-$V_6$ |
| | 4 | *Elevation* (Not routinely applied, see text)<br>S-T segment elevation of 1·0 mm. or more<br>2·0 mm. or more | <br>I, II, III, $aV_L$, $aV_5$, $V_5$, $V_6$<br>$V_1$-$V_4$ |
| V<br>T-WAVE ITEMS | 1 | T amplitude=minus 5 mm. or more ..<br>When R amplitude=5 mm. or more ..<br>When QRS mainly upright .. .. | I, II, $V_2$-$V_6$<br>$aV_L$<br>$aV_F$ |
| | 2 | T amplitude=minus 1 to 5 mm. ..<br>When R amplitude=5 mm. or more ..<br>When QRS mainly upright .. .. | I, II, $V_2$-$V_6$<br>$aV_L$<br>$aV_F$ |
| | 3 | T wave flat or small diphasic (negative phase less than 1 mm.) .. ..<br>When R amplitude=5 mm. or more ..<br>When QRS mainly upright .. .. | I, II, $V_3$-$V_6$<br>$aV_L$<br>$aV_F$ |
| VI<br>A-V CONDUCTION | 1 | Complete A-V block (permanent or intermittent) .. .. .. .. .. | any |
| | 2 | Partial A-V block .. .. .. .. | any |
| | 3 | P-R interval over 0·21 sec. (any heart rate) .. .. .. .. .. | I, II, III |
| | 4 | Accelerated conduction ("Wolff-Parkinson-White") .. .. .. .. | any |

*Continued*

CODE FOR RESTING ELECTROCARDIOGRAMS—*Continued*

| Col. | Punch | Category | Leads |
|---|---|---|---|
| VII<br>VENTRICULAR CONDUCTION | 1 | Left bundle-branch block (LBBB):<br>QRS duration 0·12 sec. or greater in ..<br>*and* R peak duration 0·06 sec. or more in any of .. .. .. .. .. | I, II, III<br>I, II, $aV_L$, $V_5$, $V_6$ |
| | 2 | Complete right bundle-branch block (RBBB):<br>QRS duration 0·12 sec. or greater in ..<br>*and* R prime greater than R in .. .. | I, II, III<br>$V_1$ |
| | 3 | Incomplete RBBB:<br>R prime greater than R *and* QRS duration less than 0·12 sec. .. .. ..<br>(report under $III_2$ if these criteria are met) | $V_1$ |
| | 4 | Intraventricular block:<br>QRS 0·12 sec. or more *and* no LBBB or RBB pattern .. .. .. .. | I, II, III |
| VIII<br>ARRHYTHMIAS | 0 | Any combination of arrhythmias below (for punch card purposes) | |
| | 1 | Frequent (4 or more in 40 complexes) premature atrial, nodal, or ventricular beats | |
| | 2 | Ventricular tachycardia (over 100/min.) | |
| | 3 | Atrial fibrillation or flutter | |
| | 4 | Supraventricular tachycardia | |
| | 5 | Ventricular (idioventricular) rhythm (up to 100/min.) | |
| | 6 | A-V nodal rhythm (up to 100/min.) | |
| | 7 | Sinus tachycardia (over 100/min.) | |
| | 8 | Sinus bradycardia (under 50/min.) | |
| | 9 | Arrhythmias not mentioned above | |
| IX<br>MISCELLANEOUS | 0 | Combinations below of Item 2 or 3 with Item 1, 2, 3, 4, 5, or 6 (for punch card purposes) | |
| | 1 | Low QRS amplitude (in I, II, III, no positive or negative deflection over 5 mm. *or* maximum QRS amplitude less than 10 mm. in $V_1$-$V_6$ | |
| | 2 | "Qualitative" T wave findings including "high" or peaked T, post-extrasystolic T wave inversion, T notching, etc. | |
| | 3 | QRS findings not mentioned above, including notching, slurring, RR prime, rotation, or others | |

*Continued overleaf*

CODE FOR RESTING ELECTROCARDIOGRAMS—*Continued*

| Col. | Punch | Category |
|---|---|---|
| IX | 4 | Prolonged Q-T interval (evaluated from kQT) |
| MISCELLANEOUS—*Continued* | 5 | P wave findings including peaked, negative, 3 mm. amplitude or over, or others |
| | 6 | Negative U wave in $V_3$-$V_6$ |
| | 7 | Other items not mentioned above |
| | 8 | Questionable category due to technical imperfections in record or beat-to-beat variability of measurement |
| | 9 | Combinations above of Item 7 or 8 with Item 1, 2, 3, 4, 5, or 6 (for punch card purposes) |