

# Clinical Significance of Upsloping ST Segments in Exercise Electrocardiography

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**SUMMARY** Conventional exercise electrocardiographic criteria usually involve patterns with a horizontal or downsloping ST segment. In the present study we present criteria based on upsloping ST segments and compared these criteria with the conventional criteria. Using upsloping ST-segment criteria, the amount of ST-segment depression at 80 msec after the end of the QRS complex is used as a parameter (ST criterion E, with a depression of 100 mV, and ST criterion F, with a depression of 200 mV). In the graded exercise test a bicycle ergometer was used. The ECG leads were CM<sub>s</sub> and CC<sub>s</sub>. The results of exercise electrocardiography were compared with the findings from coronary arteriography.

In 623 selected patients (565 males and 58 females), application of conventional ST criteria gave a sensitivity of 56% and a specificity of 94%; with application of the ST criteria E or F, sensitivity was 75% and specificity 90%. In the 58 females use of these new criteria resulted in a sensitivity of 76% and specificity of 88%. Ninety-three patients (15%) could be classified as positive exercise responders by the sole presence of an upsloping ST segment (type E or F). Sixty-eight percent of the patients with type E and 75% with type F had two- or three-vessel disease (coronary obstructions  $\geq 50\%$ ). We conclude that ST criteria based on upsloping ST segments significantly increase the diagnostic yield of the exercise ECG.

**THE SIMPLEST TECHNIQUE** to confirm the presence of coronary insufficiency is exercise electrocardiography. If applied to a population of symptomatic subjects suspected of having obstructive coronary artery disease, the specificity of the exercise ECG is rather high, but the sensitivity is relatively low.

Several methods have been investigated to improve the sensitivity, with special emphasis on the intensity of work load<sup>1-5</sup> and the selection of optimal leads.<sup>1, 6</sup> Recently,<sup>7-9</sup> new electrocardiographic criteria have been proposed that promise improved diagnostic sensitivity of the exercise ECG.

In this study we evaluated these new criteria in a test population and compared the results with those from conventional exercise electrocardiographic criteria.

### Methods

#### Patients

Patients included in this study met the following criteria: 1) a normal repolarization pattern in the standard 12-lead ECG and in the selected ECG leads when the patient was sitting at rest on the bicycle ergometer; 2) no other heart disease other than coronary artery disease; and 3) no medication that might influence the

repolarization pattern (e.g., digitalis, antiarrhythmic drugs or psychotropic drugs).

Six hundred twenty-three consecutive cases were thus collected for this study, 565 males (mean age  $50 \pm 8$  years) and 58 females (mean age  $51 \pm 10$  years). These patients were investigated because of chest pain possibly due to coronary insufficiency. One hundred seven patients had pathologic Q waves in the standard 12-lead ECG.

#### Exercise Protocol

A calibrated bicycle ergometer was used. The initial external work load was 60 W during 3 minutes; thereafter the load was increased every 3 minutes by 30 W until one of the stop criteria was fulfilled. Electrocardiographic recordings of the chest leads CM<sub>s</sub> and CC<sub>s</sub> were made by a commercially available ink-jet recorder (Mingograph type 34). The recordings were made before the exercise test with the patient in the sitting position, every 3 minutes at the end of each exercise stage and then every minute during the first 5 minutes of recovery. The following criteria for exercise termination were used: angina, exhaustion, dyspnea, dizziness, disturbances of rhythm (repetitive extrasystoles or tachycardias) or conduction (bundle branch block or atrioventricular conduction problems), a fall in systolic blood pressure compared with an earlier stage of effort, or an ischemic ST depression with a junction depression of at least 0.2 mV and 80 msec long.

In the beginning of this study (first 290 patients) the exercise test was stopped when the patient achieved 90% of age-predicted maximal heart rate;<sup>2</sup> recently, heart rate has not been used as a criterion for terminating the test.

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### Electrocardiographic Criteria

Several ST-segment patterns were investigated to assess their value in predicting significant coronary artery disease.

A distinction was made between conventional and new criteria. The conventional criteria were: a junctional depression of at least 0.1 mV followed by a horizontal or downsloping ST segment of at least 80 msec duration (fig. 1, type B, C or D). Empirically, deeper J-point depression and a downsloping ST-segment were considered to represent more severe forms of ischemia (fig. 1, type C or D).

The new criteria were: a junctional depression followed by a slowly upsloping ST segment. Two types were distinguished: Type E showed an ST depression of at least 0.1 mV 80 msec after the end of the QRS. Type F, which was considered more abnormal, showed an ST depression of at least 0.2 mV 80 msec after the end of the QRS.

An exercise ECG was considered positive if one of the above criteria was fulfilled during exercise or before the fourth minute of the recovery phase, provided that this criterion was met in at least three consecutive ECG complexes. The QQ line always served as the baseline.

If a conventional criterion was fulfilled, the test was classified according to this criterion. If a new criterion appeared in absence of a conventional criterion the test was classified according to the type of the new criterion that was considered most abnormal. The exercise ECG was always interpreted without knowledge of the coronary angiographic findings.

### Coronary Angiography

Generally, obstructions of at least 70% of the internal diameter of major coronary branches are considered to produce coronary insufficiency.<sup>10</sup> In recent studies, however, obstructions of 50% or more are considered significant.<sup>11</sup> Therefore, obstructions of at least 50% and 70%, respectively, were considered hemodynamically significant in this study. To assess

the status of the coronary circulation and to provide a yardstick for the exercise ECG criteria, all patients underwent selective coronary angiography according to Sones' technique.<sup>12</sup> Craniocaudal projections were obtained.<sup>13</sup>

The angiograms were interpreted independently by two cardiologists; disagreement was resolved independently by a radiologist. If a significant obstruction was found in one of the major branches of the coronary artery tree, the coronary angiogram (CAG) was classified as positive.

The contraction pattern of the left ventricle as visualized by the left ventricular angiogram in the right oblique projection was graded according to Gorlin's method.<sup>14</sup>

### Statistical Methods

The relation between prediction (ST change) and actual abnormality (coronary obstruction) was given in terms of sensitivity, specificity, efficiency and predictive values of a positive or negative test.<sup>15, 16</sup>

Sensitivity = true positives/(true positives + false negatives);

Specificity = true negatives/(true negatives + false positives);

Efficiency = (true positives + true negatives)/total population;

Predictive value of a positive test = true positives/all positives;

Predictive value of a negative test = true negatives/all negative tests.

The patients with true-positive results were those in whom hemodynamically significant coronary artery obstructions were predicted by a positive exercise ECG.

The patients with true-negative results were those in whom a normal CAG or CAG without significant obstructions were predicted by a negative exercise ECG.

Parametric differences were determined using the *t* test.

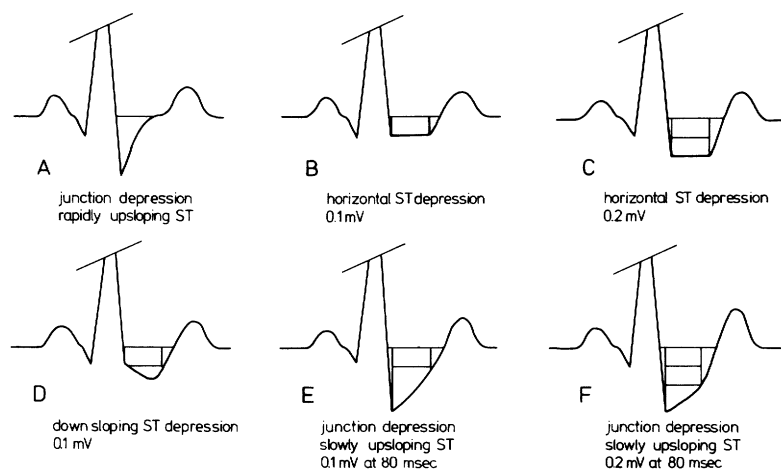


FIGURE 1. Different types of exercise-induced ST depressions. In the slowly upsloping ST-segment pattern this depression is measured 80 msec after the end of the QRS complex.

## Results

### Results of Coronary Angiography

In 138 patients the CAG either did not reveal any sign of sclerosis or presented only minor irregularities. In 38 patients the CAG revealed only obstructions of less than 50%. If an obstruction of 50% or more was considered significant, the group with positive CAGs and the group with negative CAGs consisted of 447 and 176 patients, respectively; if an obstruction of 70% or more was considered significant, the group with positive CAGs included 418 patients and the group with negative CAGs consisted of 205 patients. The grades of angiographic obstructions according to sex are given in figure 2.

### Results of Exercise Test

Subjects without coronary sclerosis ( $n = 138$ , fig. 2) reached a mean maximal heart rate of  $157 \pm 17$  beats/min. In patients with coronary obstructions of 70% or more ( $n = 418$ , fig. 2) it was  $133 \pm 21$  beats/min. There was a statistically significant difference ( $p < 0.01$ ) in maximal heart rates between these groups.

Three hundred fifty-five patients reached at least 90% of the age-predicted maximal heart rate and 182 reached 100% of the predicted maximal value. In 119 patients the exercise test was terminated because of angina, in 121 because of dyspnea or exhaustion, in eight because of ventricular arrhythmias, in one because of a bundle branch block, and in 192 because of significant ST depression.

Patients with a type E ST response ( $n = 37$ ) reached  $90 \pm 13\%$  of their age-predicted maximal heart rate; in the 56 patients who had a type F ST response, the heart rate was  $90 \pm 11\%$  of predicted maximal; patients with the conventional exercise ST criteria types B, C or D during or after exercise

TABLE 1. Comparison of Maximal Heart Rate and Total Work Load in Groups with Different Types of ST Response

| Type of ST response | No. pts | % MHR       | Total work load (watt-sec) |
|---------------------|---------|-------------|----------------------------|
| No changes or A     | 271     | $95 \pm 11$ | $1040 \pm 585$             |
| E                   | 37      | $90 \pm 13$ | $743 \pm 494$              |
| F                   | 56      | $90 \pm 11$ | $840 \pm 488$              |
| B, C or D           | 259     | $82 \pm 13$ | $660 \pm 401$              |

Abbreviation: MHR = percentage of age-predicted maximal heart rate.

( $n = 259$ ) had  $82 \pm 13\%$  of predicted maximal heart rate. Between the groups with type E and type F ST response and the group with B, C or D ST response, the differences in heart rate were statistically significant (table 1,  $p < 0.01$ ).

In table 1 the average amounts of total external work load for the different groups are listed. For this measurement, there was no statistically significant difference between the groups with type E and type F ST response or between these two groups and the group with type B, C or D ST responses.

### Results of Electrocardiographic Criteria in Relation to the Coronary Angiogram

If obstructions of 70% or more were considered significant, and conventional criteria (fig. 1, types B, C or D) were applied to the entire population, irrespective of the attained heart rate, the sensitivity was 58%, the specificity 92%, efficiency 69%, predictive value of a positive test 94% and predictive value of a negative test 52% (table 2).

If, in addition, the new criterion based on the slowly upsloping ST segment type F (fig. 1) was applied,

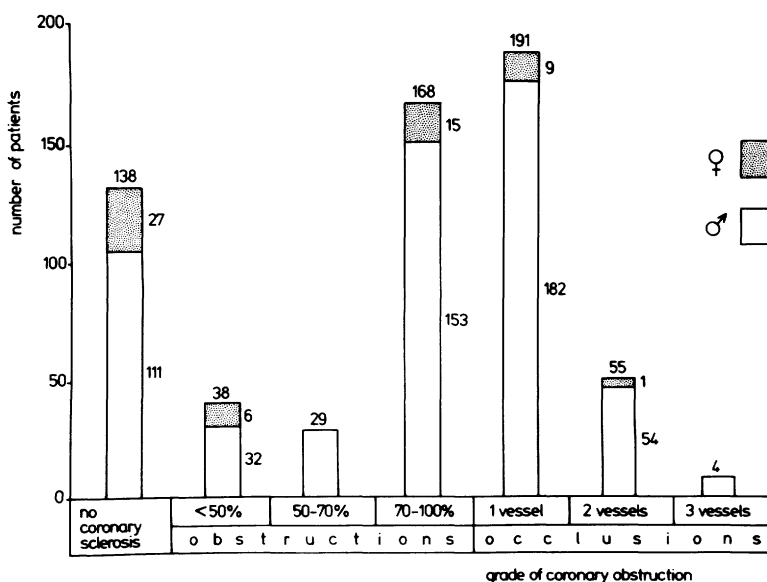


FIGURE 2. Distribution of the 623 patients according to the grade of coronary obstruction.

TABLE 2. Parameters of Test Accuracy for the Different Types of Exercise ST Responses When 50% and 70% or More Obstruction is Considered Significant, Irrespective of the Achieved Heart Rate ( $n = 623$ )

| Type of ST response | Sensitivity    | Specificity   | Efficiency     | Predictive value           |                            |
|---------------------|----------------|---------------|----------------|----------------------------|----------------------------|
|                     |                |               |                | True-positive exercise ECG | True-negative exercise ECG |
| 50% obstruction     |                |               |                |                            |                            |
| B, C or D           | 249/447 (56%)  | 166/176 (94%) | 415/623 (67%)  | 249/259 (96%)              | 166/364 (46%)              |
| B, C, D or F        | 304/447 (68%)* | 165/176 (94%) | 469/623 (75%)* | 304/315 (96%)              | 165/308 (54%)              |
| B, C, D, E or F     | 335/447 (75%)† | 159/176 (90%) | 494/623 (79%)† | 335/352 (95%)              | 159/271 (59%)*             |
| 70% obstruction     |                |               |                |                            |                            |
| B, C or D           | 243/418 (58%)  | 189/205 (92%) | 432/623 (69%)  | 243/259 (94%)              | 189/364 (52%)              |
| B, C, D or F        | 297/418 (71%)* | 187/205 (91%) | 484/623 (78%)* | 297/315 (94%)              | 187/308 (61%)              |
| B, C, D, E or F     | 328/418 (79%)† | 181/205 (88%) | 509/623 (82%)† | 328/352 (93%)              | 181/271 (67%)*             |

Statistical significance of intergroup comparisons vs type B, C or D: \* $p < 0.05$ ; † $p < 0.0005$ .

the sensitivity was significantly increased to 71% ( $p < 0.05$ ), with a specificity of 91% (NS); the efficiency of the test improved significantly to 78% ( $p < 0.05$ ), the predictive value of a positive test remained 94% and the predictive value of a negative test increased to 61% (NS). Table 2 gives the results of the measures of test accuracy if obstructions of 50–70% were included in the group with positive CAGs.

If the ST response Type E (fig. 1) was used as a positive criterion and obstructions of 70% or more were considered significant, the sensitivity improved significantly to 79%, compared with 58% by the conventional criteria type B, C or D ( $p < 0.0005$ ). The specificity decreased to 88% (NS) and the efficiency increased significantly, to 82% ( $p < 0.0005$ ); the predictive value of a positive test diminished to 93% (NS) and the predictive value of a negative test increased to 67% ( $p < 0.05$ ). Table 2 gives the results if obstructions of 50–70% were included in the group with positive CAGs.

No significant intergroup differences of the various parameters for test accuracy were found between the ST response type F, and type E or F in addition to the conventional exercise ECG criteria. The differences for test accuracy were not significantly influenced when obstructions of 50% or 70% or more were considered as positive CAGs, respectively.

For the 58 women included in the study, sensitivity was 44% and specificity 94% if only conventional exercise ECG criteria were used and if angiographic obstructions of 70% or more were considered as positive CAGs. If, in addition, the type F criterion was applied, the sensitivity rose to 60% and the specificity remained at 94%. If type E was used as a positive criterion, sensitivity rose to 76% and specificity changed to 88%. These percentages were identical if obstructions of 50% or more were considered true positive. Ninety-three patients (15%) could be classified as positive responders by the sole presence of an upsloping ST segment during exercise ( $n = 37$  for type E and  $n = 56$  for type F); 17% of the group with type E and 5% of the group with type F ST response had negative CAG, if obstructions of 70% or more

were considered positive (fig. 3). Of the 36 patients who had only an ischemic ST segment in the recovery phase (according to types B, C or D, fig. 1), 34 patients had positive CAG. Eighty-three percent of these patients already had a slowly upsloping ST segment (type E or F, fig. 1) during exercise.

#### Results of Exercise Electrocardiographic Criteria in Relation to the Severity of Coronary Sclerosis

One hundred seventy-two patients showed an obstruction of 70% or more in only one coronary vessel, 170 had such obstructions in two vessels and 66

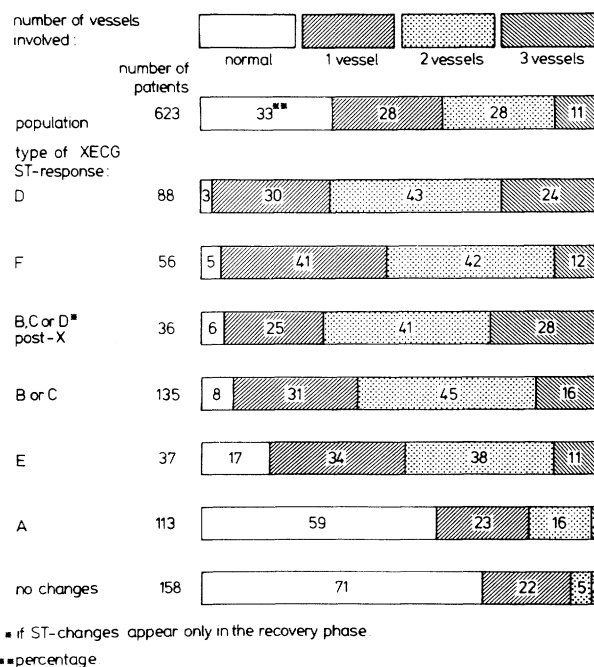


FIGURE 3. Occurrence of the different types of exercise ST depression and their relation to the number of vessels involved in 623 subjects; an obstruction of 70% or more is considered as a significant obstruction. Left main stenosis is classified as a two-vessel disease.

TABLE 3. *Relation Between the Severity of the Coronary Sclerosis and the Sensitivity of the Exercise Test When 50% and 70% or More Obstruction Is Considered Significant*

| Severity (CAG)  | 50% obstruction |              |        | 70% obstruction |              |        |
|-----------------|-----------------|--------------|--------|-----------------|--------------|--------|
|                 | No. pts         | Sensitivity* |        | No. pts         | Sensitivity* |        |
|                 |                 | F            | E or F |                 | F            | E or F |
| 1 vessel        | 116             | 45%          | 50%    | 172             | 58%          | 65%    |
| 2 vessels       | 176             | 66%          | 76%    | 170             | 78%          | 86%    |
| Left main       | 6               | 67%          | 67%    | 7               | 85%          | 85%    |
| 3 vessels       | 132             | 87%          | 94%    | 66              | 86%          | 92%    |
| Left main + RCA | 17              | 100%         | 100%   | 3               | 100%         | 100%   |
| Total           | 447             | 68%          | 75%    | 418             | 71%          | 79%    |

\*When type F or type E or F are considered as a true-positive ECG, in addition to the conventional ST criteria.

Abbreviations: CAG = coronary arteriogram; RCA = right coronary artery.

in three vessels (left-main-stem obstructions are considered separately below); 58%, 78% and 86% of the patients from these groups had true-positive exercise ECGs when ST types B, C, D or F were considered positive criteria. If, in addition, type E was applied as a positive criterion these percentages were 65%, 86% and 92%, respectively (table 3).

Sixty-seven percent of the patients with type D ST response, 61% with B or C, 54% with type F and 49% with type E ST response had two- or three-vessel disease, if obstructions of 70% or more were considered positive by CAG (fig. 3). If an obstruction of 50% or more was considered positive by CAG, these percentages were 85%, 78%, 75% and 68%, respectively. Eighty-six patients had an isolated obstruction of 70% or more in the anterior descending artery, 34 had such obstruction of the circumflex artery and 52 of the right coronary artery. The sensitivity of the exercise ECG in these groups was 53%, 62% and 63%, respectively, when types B, C, D or F were considered as positive by ECG, and 63%, 65% and 69%, respectively, if in addition, type E was used to indicate positive exercise ECG results (table 4).

Twenty-three patients had a left-main-stem obstruction of 50% or more and 17 of these had also an obstruction of 50% or more of the right coronary artery. Ten patients had left-main-artery obstruction

of 70% or more, and three also had a right coronary obstruction of 70% or more. With application of the criterion type F (fig. 1) in addition to the conventional exercise ECG criteria, the sensitivity in cases of left-main-artery obstructions of 50% and 70% or more was 67% and 85%, respectively. If there was also a right coronary artery obstruction, the sensitivity rose to 100%. These percentages were identical if ST type E also was considered positive by exercise ECG (table 3).

#### Influence of the Heart Rate on the Diagnostic Accuracy of the Exercise Test

Five hundred sixty-two patients either attained 90% of their age-predicted maximal heart rate or showed an exercise ST response type B, C, D, E or F; 550 either attained this heart rate or showed an ST response type B, C, D or F, and 529 patients either achieved this heart rate or showed a conventional ST response type B, C or D. The influence of higher heart rates on the parameters of test accuracy are listed in table 5, for both 50% and 70% obstructions as the limits of a positive CAG.

Application of type F and types E or F in addition to the conventional ST-criteria B, C or D to cases with 70% obstruction or more significantly increased the

TABLE 4. *Sensitivity of the Exercise Test in Isolated One-vessel Disease When 50% and 70% or More Obstruction Is Considered Significant*

| Vessel | 50% obstruction |              |        | 70% obstruction |              |        |
|--------|-----------------|--------------|--------|-----------------|--------------|--------|
|        | No. pts         | Sensitivity* |        | No. pts         | Sensitivity* |        |
|        |                 | F            | E or F |                 | F            | E or F |
| LAD    | 62              | 40%          | 45%    | 86              | 53%          | 63%    |
| LCX    | 24              | 46%          | 54%    | 34              | 62%          | 65%    |
| RCA    | 30              | 57%          | 57%    | 52              | 63%          | 69%    |
| Total  | 116             | 45%          | 50%    | 172             | 58%          | 65%    |

\*When type F and type E or F are considered as positive exercise ECG in addition to the conventional ST criteria.

Abbreviations: LAD = left anterior descending artery; LCX = left circumflex artery; RCA = right coronary artery.

TABLE 5. Parameters of Test Accuracy for the Different Types of Exercise ST Response When 50% and 70% or More Obstruction is Considered Significant

| Type of ST response | Sensitivity    | Specificity   | Efficiency     | Predictive value           |                            |
|---------------------|----------------|---------------|----------------|----------------------------|----------------------------|
|                     |                |               |                | True-positive exercise ECG | True-negative exercise ECG |
| 50% obstruction     |                |               |                |                            |                            |
| B, C or D           | 249/375 (66%)  | 144/154 (93%) | 393/529 (74%)  | 249/259 (96%)              | 114/270 (53%)              |
| B, C, D or F        | 304/396 (77%)* | 143/154 (93%) | 447/550 (81%)† | 304/315 (96%)              | 143/235 (61%)              |
| B, C, D, E or F     | 335/407 (82%)§ | 138/155 (89%) | 473/562 (84%)‡ | 335/352 (95%)              | 138/210 (66%)†             |
| 70% obstruction     |                |               |                |                            |                            |
| B, C or D           | 243/351 (69%)  | 162/178 (91%) | 405/529 (77%)  | 243/259 (94%)              | 162/270 (60%)              |
| B, C, D or F        | 297/372 (80%)* | 160/178 (90%) | 457/550 (83%)† | 297/315 (94%)              | 160/235 (68%)              |
| B, C, D, E or F     | 328/383 (86%)§ | 155/179 (87%) | 483/562 (86%)‡ | 328/352 (93%)              | 155/210 (74%)†             |

Only patients are included who reach at least 90% of their age-predicted maximal heart rate or show any of the ST responses (B, C, D, E or F).

Statistical significance of intergroup comparisons vs type B, C or D: \* $p < 0.1$ ; † $p < 0.5$ ; ‡ $p < 0.005$ ; § $p < 0.0005$ .

sensitivity of the exercise ECG from 69% to 80% ( $p < 0.1$ ) and from 69% to 86% ( $p < 0.0005$ ), respectively, without appreciable loss of specificity. The results show the same tendency for obstructions of 50%. No significant intergroup differences of the parameters of test accuracy were found between the ST response type F and type E or F in addition to the conventional exercise ECG criteria, or between cases with an obstruction of at least 50% and those with 70% or more obstruction (table 5).

When 90% of the maximal heart rate was not considered, the sensitivity rose from 56% to 66% if only patients who reached at least 90% of the age-predicted maximal heart rate were included ( $p < 0.1$ ), and if ST criteria B, C or D were considered in predicting obstructions of 50% or more. If type F and type E or F were considered positive exercise ECG, the sensitivity increased from 68% to 77% ( $p < 0.25$ ) and from 75% to 82% ( $p < 0.5$ ), respectively, without significant loss of specificity. When obstructions of 70% or more were considered as positive by CAG, an analogous increase in sensitivity was found with the same statistical significance and no loss of specificity.

#### Influence of Left Ventricular Contraction Pattern on the Sensitivity of the Exercise Test

Of the 372 patients with angiographic obstructions of 70% or more who either reached 90% of the age-predicted maximal heart rate or showed type B, C, D or F ST response, 259 had a normal and 113 an abnormal contraction pattern of the left ventricle. The sensitivity of the exercise ECG in these groups was 82% (212 of 259) and 75% (85 of 113), respectively.

Of the 383 patients who reached that heart rate or showed type B, C, D, E or F ST-response, 264 had a normal and 119 an abnormal contraction pattern with a sensitivity of the exercise ECG of 88% (223 of 264) and 80% (95 of 119), respectively. If obstructions of 50% or more were considered as positive CAGs 396 patients reached 90% of the predicted maximal heart rate or showed type B, C, D or F ST response; 280

patients had a normal and 116 an abnormal contraction pattern of the left ventricle, with a sensitivity of 78% (218 of 280) and 74% (86 of 116), respectively. Of the 407 patients who reached that heart rate or showed type B, C, D, E or F ST response 286 had a normal and 121 an abnormal contraction pattern, the sensitivity was 84% (240 of 286) and 78% (95 of 121), respectively. None of these differences were statistically significant.

#### Discussion

The appearance during exercise of junctional depression followed by a slowly upsloping ST segment is of diagnostic importance, as emphasized by Punsar et al. The method of measuring the ST slope, however, resulted in relatively high inter- and intraobserver variability.<sup>17</sup> Recently, computerized analysis of such ST configurations has brought additional diagnostic information about the visual method.<sup>18-20</sup>

Stuart and Ellestad introduced a method that makes it possible to classify visually such slowly upsloping ST segments. In this method the ST depression is measured 80 msec after the end of the QRS complex.<sup>7</sup> Several studies support the reproducibility of the measurements.<sup>7-9</sup>

In our study the diagnostic value of the conventional exercise ECG criteria has been compared with new criteria based on slowly upsloping ST segments. By applying these criteria the sensitivity of the exercise ECG has been increased significantly compared with the conventional ST criteria. In predicting obstructions of 50% and 70% or more, the sensitivity was enhanced another 12% and 13%, respectively, using ST criterion type F, and by 19% and 20%, respectively, using ST criterion type E in addition to types B, C, D or F, without significant loss of specificity. Isolated appearance of the ST configurations E or F (15% of the entire population) occurred at significantly higher heart rates than when the conventional ST configurations B, C or D also appeared; 83% of the patients who showed only an ischemic ST

response in the recovery stage already had type E or F ST response during exercise. ST configurations E or F should be regarded as precursors of the ST configurations B, C or D. Use of ST criteria E or F allowed detection of more patients with severe coronary sclerosis: 68% and 75% of the type E and F responses, respectively, had two- or three-vessel disease when obstructions of 50% or more were considered as positive CAG results.

Use of criteria E or F for detecting significant multivessel obstructions is only slightly inferior to that of conventional exercise ECG criteria. This is in accordance with the findings of Stuart and Ellestad.<sup>7</sup> The diagnostic performance of the described ST criteria may be expected to be similar in other studies, provided that the patient populations were selected in a comparable way. In a group of patients comparable to that of our study, Kurita et al.,<sup>8</sup> applying the type F ST criterion, obtained analogous results (table 6). Our study was in part designed as a control study for evaluating this criterion and our findings confirm the diagnostic performance of the ST criterion type F. Goldschlager et al.<sup>9</sup> reported on a symptomatic population in which the measurement of slowly upsloping ST segments lead to a sensitivity of 76% with a somewhat lower specificity of 82%, compared with the study of Kurita et al. and this study. In the former study a criterion of 1.5 mV has been used for ST-depression measurement. If we adopt 1 mV as the critical value for the upsloping ST depression (type E) in our series, we find a significant increase in sensitivity with respect to criteria B, C or D, but not with respect to criteria B, C, D or F. For this reason and because of the lack of control studies on this criterion with data on sensitivity and specificity, we would not advise the use of the ST criterion type E when the results of exercise electrocardiography are only classified as positive or negative.

The results with the new criteria are almost equivalent to those obtained with computer-assisted techniques.<sup>18-20</sup> However, whether computerized analysis provides further benefits remains to be settled by studies in which both techniques are applied to the same population. Despite the favorable results of the new criteria there are still many patients with severe coronary artery disease who have a negative exercise ECG. Adequate collateral circulation in cases with severe coronary artery obstructions or occlusions may provide a sufficient reserve during exercise and therefore it is to be expected that false-negative results will occur in exercise electrocardiography. However, it is very difficult to quantify such collateral circulation by angiography. Many patients with false-negative exercise ECGs have one-vessel disease. In the group of patients with an obstruction of 70% or more in only one vessel, the percentage of false-negative tests were 42% if ST type F was present. This percentage fell to 14% in three-vessel disease. Some studies have shown that the exercise ECG is more sensitive to detect isolated stenoses of the left anterior descending artery.<sup>6, 18</sup> Other investigations, including the present study, have not confirmed this.<sup>9, 21, 22</sup> Perhaps the

TABLE 6. Comparison of the Diagnostic Results in Two Studies in Which the Criterion of the Slowly Upsloping ST Segment Type F is Applied when 50% and 70% or More Obstruction is Considered Significant

| Type of ST response | Author                     | Sensitivity |     | Specificity |     |
|---------------------|----------------------------|-------------|-----|-------------|-----|
|                     |                            | 50%         | 70% | 50%         | 70% |
| B, C or D           | Kurita et al. <sup>8</sup> | 55%         | 58% | 98%         | 96% |
|                     | This study                 | 66%         | 69% | 93%         | 91% |
| B, C, D or F        | Kurita et al. <sup>8</sup> | 77%         | 83% | 95%         | 92% |
|                     | This study                 | 77%         | 80% | 93%         | 90% |

Only patients are included who reach 90% of their age-predicted maximal heart rate or showed any of the ST responses (B, C, D or F).

localization of the obstruction, more distal or proximal in the affected vessel, may be the cause.<sup>23</sup>

As expected, the sensitivity of the exercise ECG in predicting coronary obstructions of 70% or more was slightly higher than in predicting obstructions of 50% or more, but with the concomitant fall in specificity these differences were not statistically significant. The sensitivity of the exercise ECG can be increased by higher work loads, resulting in higher heart rates.<sup>4</sup> When the inadequate tests were excluded from subsequent analysis, i.e., if only exercise tests were included in which at least 90% of the age-predicted maximal heart rate was achieved, the sensitivity increased significantly, when in addition the criteria E or F were also applied. Several authors<sup>24-26</sup> have reported that many patients with signs of prior myocardial infarction as determined from the ECG and/or left ventricular angiography have a false-negative exercise ECG. In our study, however, the sensitivity for patients with wall motion abnormalities on the angiogram is not significantly different from the sensitivity for those with a normal contraction pattern. Other investigators advise the use of multiple leads to increase the sensitivity of the exercise ECG.<sup>1, 6</sup> Our previous studies suggest that a combination of leads like CM<sub>5</sub> and CC<sub>5</sub> gives a high diagnostic score in detecting ischemic heart disease.<sup>5, 27</sup> The vectorcardiographic leads X, Y and Z are not better than this combination as far as patients with a normal repolarization pattern at rest were concerned.<sup>27, 28</sup> The study of Chaitman et al.<sup>6</sup> showed that leads CM<sub>5</sub> and CC<sub>5</sub> also give a high diagnostic score if the new criterion type F is applied. However, the use of multiple leads may result in a lower specificity. The use of multiple leads or vectorial components was not more useful in predicting the localization of the coronary obstructions in cases of isolated obstructions.<sup>18, 21, 27, 29</sup>

The criteria based on slowly upsloping ST segments were highly specific in the female patients in our study; the sensitivity may be lower than for the total population, but the additional value compared with the conventional criteria shows the same tendency. An impor-



tant prerequisite for applying these criteria to females is the presence of a normal repolarization pattern at rest, in both the recumbent and sitting positions.<sup>30</sup>

We conclude that the analysis of the slowly upsloping ST segment during exercise contributes to the detection of ischemic heart disease and should be included in a grading system of exercise electrocardiography.<sup>31</sup>

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### References

- Mason RE, Likar IL, Biern RO, Ross RS: Multiple-lead exercise electrocardiography. *Circulation* **36**: 517, 1967
- Sheffield LT, Holt JH, Reeves TJ: Exercise graded by heart rate in electrocardiographic testing for angina pectoris. *Circulation* **32**: 622, 1965
- Bellet S, Roman L: Comparison of the double two step test and the maximal exercise treadmill test. *Circulation* **36**: 238, 1967
- Cumming GR: Yield of ischaemic exercise electrocardiograms in relation to exercise intensity in a normal population. *Br Heart J* **34**: 919, 1972
- Ascoop CA, Simoons ML, Egmond WG, Bruschke AVG: Exercise test, history and serum lipid levels in patients with chest pain and normal electrocardiogram at rest. Comparison to findings at coronary arteriography. *Am Heart J* **82**: 609, 1971
- Chaitman BR, Bourassa MG, Wagniat P, Corbara F, Ferguson RJ: Improved efficiency of treadmill exercise testing using a multiple lead ECG system and basic hemodynamic exercise response. *Circulation* **57**: 71, 1978
- Stuart RJ, Ellestad MH: Upsloping ST segments in exercise stress testing. *Am J Cardiol* **37**: 19, 1976
- Kurita A, Chaitman RB, Bourassa MG: Significance of exercise-induced junctional ST-depression in evaluation of coronary artery disease. *Am J Cardiol* **40**: 492, 1977
- Goldschlager N, Selzer A, Cohn K: Treadmill stress test as indicator of presence and severity of coronary artery disease. *Ann Intern Med* **85**: 277, 1976
- Logan SE: On the fluid mechanics of human artery stenosis. *IEEE Trans Biomed Eng* **22**: 1975
- Cohn K, Kamm B, Feteith N, Brand R, Goldschlager N: Use of treadmill score to quantify ischemic response and predict extent of coronary disease. *Circulation* **59**: 286, 1979
- Sones FM, Shirey EK: Cine coronary arteriography. *Mod Concepts Cardiovasc Dis* **31**: 735, 1962
- Ludwig JW, Bruschke AVG: Improvement of the diagnostic accuracy of the coronary arteriogram by unconventional projections. *Circulation* **47** (suppl IV): IV-193, 1973
- Gorlin R, Klein MD, Sullivan JM: Prospective correlative study of ventricular aneurysms, mechanistic concept and clinical recognition. *Am J Med* **42**: 512, 1967
- Yerushalmy J: Statistical problems in assessing methods of medical diagnosis. *Pub Health Rep* **62**: 1432, 1947
- Galen RS: Predictive value of laboratory tests. *Am J Cardiol* **36**: 536, 1975
- Punsar S, Pyörälä K, Siltanen P: Classification of electrocardiographic ST-segment changes in epidemiological studies of coronary heart disease. *Ann Intern Med Fenn* **57**: 53, 1968
- McHenry PL, Phillips JF, Knoebel SB: Correlation of computer-quantitated treadmill exercise electrocardiogram with arteriographic location of coronary artery disease. *Am J Cardiol* **30**: 747, 1972
- Ascoop CA, Distelbrink CA, De Lang PA: Clinical value of quantitative analysis of ST slope during exercise. *Br Heart J* **39**: 212, 1977
- Distelbrink CA, De Lang PA, Ascoop CA, Block P, Simoons ML: *In Trends in Computer-processed Electrocardiograms*, edited by JH Van Bommel, JL Willems. Amsterdam, North Holland Publishing Co, 1977
- Kaplan MA, Harris CN, Aronow WS, Parker DP, Ellestad MH: Inability of the submaximal treadmill stress test to predict the location of coronary disease. *Circulation* **47**: 250, 1973
- Bartel AG, Behar VS, Peter RH, Orgain ES, Kong Y: Graded exercise stress tests in angiographically documented coronary artery disease. *Circulation* **49**: 348, 1974
- Tonkon MJ, Miller RR, DeMaria AN, Vismara LA, Amsterdam EA, Mason DT: Multifactor evaluation of the determinants of ischemic electrocardiographic response to maximal treadmill testing in coronary disease. *Am J Med* **62**: 339, 1977
- Kramer N, Susmano A, Shekelle RB: The false negative treadmill exercise test and left ventricular dysfunction. *Circulation* **57**: 763, 1978
- Cestellanet MJ, Greenberg PS, Ellestad MH: Comparison of ST-segment changes on exercise testing with angiographic findings in patients with prior myocardial infarction. *Am J Cardiol* **42**: 29, 1978
- Kasser IS, Bruce RA: Comparative effects of aging and coronary heart disease on submaximal and maximal exercise. *Circulation* **39**: 759, 1969
- Ascoop CA, Distelbrink CA, De Lang P, Van Bommel JH: Quantitative comparison of exercise vectorcardiograms and findings at selective coronary arteriography. *J Electrocardiol* **7**: 9, 1974
- Robertson D, Kostuk WJ, Ahuja SP: The localization of coronary artery stenosis by 12-lead response to graded exercise test: support for intercoronary steal. *Am Heart J* **91**: 437, 1976
- Linhardt JW, Laws JG, Satinsky JD: Maximal treadmill exercise electrocardiography in female patients. *Circulation* **50**: 1173, 1974
- Selzer A, Cohn K, Goldschlager N: On the interpretation of exercise test. *Circulation* **58**: 193, 1978