Effect of ST Segment Measurement Point on Performance of Standard and Heart Rate–Adjusted ST Segment Criteria for the Identification of Coronary Artery Disease

Peter M. Okin, MD; Geoffrey Bergman, MD; and Paul Kligfield, MD

Background. Recent reports critical of the performance of heart rate–adjusted indexes of ST depression during exercise electrocardiography have used J-point rather than ST segment measurements. However, no standard exists for the optimal time after the J-point at which to measure ST segment deviation.

Methods and Results. To assess the effect of ST segment measurement position on performance of standard exercise electrocardiographic criteria, the ΔST segment/heart rate (ΔST/HR) index, and the ST segment/heart rate (ST/HR) slope for the detection of coronary artery disease, the exercise electrocardiograms of 50 clinically normal subjects and 80 patients with known or likely coronary disease were analyzed using ST depression measured at both the J-point and at 60 msec after the J-point (J+60). A positive exercise electrocardiogram by standard criteria, defined as 0.1 mV or more of additional horizontal or downsloping ST depression at end exercise, had a specificity of 96% when ST depression was measured at either the J-point or J+60. There was no difference in sensitivity of standard electrocardiographic criteria at J+60 and J point (both 59%, p:NS). However, at matched specificity of 96%, the ΔST/HR index and ST/HR slope calculated using ST depression at J+60 were significantly more sensitive (90% and 93%) than when calculated using J-point depression (64% and 61%, each p<0.001). Comparison of areas under respective receiver operating characteristic curves confirmed the superior performance of J+60 as opposed to J-point measurements for both the ΔST/HR index (0.98 versus 0.89, p=0.006) and the ST/HR slope (0.96 versus 0.87, p=0.007) and also demonstrated modestly improved overall test performance for standard electrocardiographic criteria using J+60 measurements (0.88 versus 0.82, p=0.001).

Conclusions. Use of J-point measurements significantly degrades performance of heart rate–adjusted indexes of ST depression but has less effect on standard criteria. (Circulation 1991;84:57–66)
HR) slope for the detection of coronary artery disease and to determine an optimal ST segment measurement point for these criteria.

**Methods**

**Study Population**

One hundred thirty consecutively studied subjects and patients who met criteria outlined below were entered into one of three clinical groups, one with a low likelihood of coronary disease and two with a high (or certain) likelihood of disease. All subjects or patients were analyzed separately specifically for the purpose of this study; none had been included in previous reports of these methods. All subjects and patients were assigned to one of the clinical groups before examination of the exercise electrocardiogram, and no individual was excluded after group assignment.

*Normal subjects.* There were 50 normal subjects (group 1, 40 men and 10 women) whose mean age was 48±10 (mean±SD) years. There were no volunteer subjects in this group, and each was referred by his physician for exercise electrocardiography as part of a comprehensive screening evaluation or as a precautionary evaluation before beginning an exercise program. All subjects were free of chest pain, had no history of cardiac disease, were not taking medications, and had normal cardiac physical examinations, normal blood pressure, and normal resting electrocardiograms. In addition, all subjects were free of chest pain during treadmill exercise. Based on the data of Diamond et al.30 and Diamond and Forrester,31 the age- and sex-adjusted likelihood of coronary disease in this asymptomatic group can be estimated as no more than 0.05.

*Patients with clinical angina.* There were 50 patients with clinical angina (group 2, 28 men and 22 women) whose mean age was 62±10 years. Each was referred by a physician for exercise electrocardiography to evaluate clinically stable retrosternal chest discomfort that was consistently provoked by exertion and relieved by rest. In addition, all patients in this group developed typical chest discomfort during treadmill exercise. Patients with left bundle branch block or myocardial infarction within 8 weeks were not included. Five patients had resting electrocardiographic evidence of previous Q wave myocardial infarction, and five patients had electrocardiographic evidence of left ventricular hypertrophy. There were 26 patients who were not taking medications; among the remaining 24 patients, 12 were taking β-blocking drugs, nine were taking nitrates, and 12 were taking calcium channel blockers at the time of exercise testing. The age- and sex-adjusted likelihood of coronary disease in this group can be estimated at no less than 0.93.30,31

*Patients with catheterization-proved coronary disease.* There were 30 patients with coronary disease proved by catheterization (group 3, 25 men and 5 women) whose mean age was 62±10 years. All patients in this group had stable, effort-related chest pain that was relieved by rest, and each patient was referred by a physician for exercise testing and coronary arteriography. Patients with left bundle branch block or recent myocardial infarction were also excluded. There were two patients with electrocardiographic evidence of Q wave myocardial infarction and three with evidence of left ventricular hypertrophy. There were nine patients who were unmedicated; among the remaining 21 patients, 16 were taking β-blocking drugs, 11 were taking nitrates, and 11 were taking calcium channel blocking drugs at the time of exercise evaluation.

**Exercise Electrocardiography**

Exercise electrocardiograms were performed on a treadmill using a Q5000 computerized exercise system (Quinton Instrument Co., Seattle), modified by the addition of a bipolar lead CM5 to the standard 12-lead recording system. All patients exercised according to the Cornell protocol,32 our more gently graded modification of the Bruce protocol that produces the small heart rate increments between stages necessary for accurate determination of the ST/HR slope.10,19 Age-adjusted target heart rates were sought as the exercise end point for all studies, but tests were terminated when necessary because of limiting chest pain, dyspnea, or fatigue. After each minute of exercise and at peak exercise, 2.5 seconds of raw signal from each lead except aVR was recorded in the standard manner.

In addition to providing standard electrocardiographic output during exercise, the Q5000 system provides computer-based measurement of ST segment levels in each lead, based on arithmetic averaging of the previous 20 seconds of normal complexes, with amplitude of the digitized waveform updated every 10 seconds.33 Computer-calculated ST segment amplitudes, measured to the nearest 10 μV at a point 60 msec after the J-point with the end of the PR segment as a reference, were obtained in each lead after each stage of exercise and at peak exercise; accuracy of this measurement has been previously validated in our laboratory.33 After completion of each test, digitized waveforms and heart rate data were saved to diskette for subsequent remeasurement of the magnitude of ST segment depression throughout exercise at 0, 20, 40, and 80 msec after the J-point and recalculation of end-exercise criteria using each measurement.

Exercise tests were evaluated using standard electrocardiographic criteria based on the measured amount of ST segment depression on the peak exercise electrocardiogram.17 The test was considered positive in the presence of 0.1 mV (100 μV) of additional horizontal or downsloping ST segment depression. The test was considered negative in the presence of any amount of upsloping ST segment depression or if less than 0.1 mV additional horizontal or downsloping ST segment depression was present at end exercise.17,21 For determination of both standard and heart rate–adjusted criteria, only ST segment depression was used; all ST
Definitions of test sensitivity and specificity conform to standard use. Test specificity at each measuring point was defined in the 50 clinically normal subjects (group 1). Because of the highly referred nature of our angiography population, and the known and potential effects of referral bias on selection for angiography, test sensitivity was assessed in all 80 patients with known or suspected coronary disease (groups 2 and 3). Comparison of test sensitivity of standard test criteria, ST segment depression at peak exercise, the ΔST/HR index, and the ST/HR slope was performed at the matched specificity of 96% found for standard criteria, using McNemar's modification of the χ2 method for paired proportions. Because sensitivity and specificity of a test are dependent on the partition value chosen for test positivity, test accuracy of standard test criteria, ST segment depression, the ΔST/HR index, and the ST/HR slope were also compared using receiver operating characteristic (ROC) curve analysis. ROC curves compare sensitivity and specificity of a test over a wide range of possible partition values and can be used to compare differences between methods independent of empirically derived criteria. ROC curves were compared statistically by means of a univariate Z test of the difference between the areas under two ROC curves. Test performance for each method using ST measurements at 0, 20, 40, and 80 msec after the J-point was compared with performance of that test using ST measurements at 60 msec after the J-point. Test performance of the ST/HR slope and ΔST/HR index was then compared with test performance of standard test criteria and with performance of ST segment depression magnitude alone at each time after the J-point.

Mean values for all findings are reported with the standard deviation as the index of dispersion. Comparison of mean values between and among groups was performed by one-way analysis of variance, with post hoc testing of individual group differences by Scheffe's method. Comparison of subgroup proportions was performed by χ2 analysis with correction for continuity. For all comparisons, a value of p<0.05 was required for rejection of the null hypothesis.

Results

Group Characteristics and Exercise Performance

Group characteristics and exercise performance are shown in Table 1. Normal subjects were younger, exercised longer, and achieved higher heart rates and greater peak systolic blood pressures than did patients with typical angina or patients with proved coronary disease. Among patients with known or suspected coronary disease, patients referred to angiography and found to have coronary disease were more commonly men, exercised for a shorter duration, and achieved lower percentage of target heart rates, maximum heart rates, and maximum systolic blood pressures than did patients with typical angina. However, sex distribution was similar in clinically normal subjects and in patients.
with coronary disease at angiography, and patients with coronary disease were in turn similar in age to patients with clinical angina.

Effect of ST Measurement Position on the Magnitude of ST Segment Depression

The relation of the time after the J-point at which ST depression is measured to the magnitude of ST segment depression at peak exercise is examined in Table 2. In normal subjects, the magnitude of ST depression was significantly affected by the time of measurement; there was significantly greater mean ST depression at 0, 20, or 40 msec after the J-point than when ST depression was measured at 60 msec after the J-point, and there was a highly significant relation between decreasing ST depression and increasing delay of ST measurement after the J-point ($p<0.001$). There was a similar relation in patients with angina ($p<0.001$), but only mean ST depression measured at 0 and 20 msec after the J-point were significantly different from mean ST depression at J+60. In contrast, there was no significant difference in ST depression at the various measurement times after the J-point among patients with proven coronary disease.

Between-group differences in ST segment depression at peak exercise according to ST segment measurement point are also examined in Table 2. When measured between 40 and 80 msec after the J-point, mean ST segment depression was significantly greater among patients with proven coronary disease than among patients with clinical angina or normal subjects and was significantly higher among patients with clinical angina than among normal subjects. In contrast, when ST segment depression was measured at the J-point, there was no significant difference in ST segment depression between normal subjects and patients with clinical angina or between patients with clinical angina and those with proven coronary disease, with much less of a difference in peak ST depression between group 1 and group 3 than at other measurement points.

Effect of ST Measurement Position on Test Accuracy of Standard Criteria and ST Segment Depression

The specificity and sensitivity of standard test criteria at a fixed partition value of 0.1 mV were unaffected by the time after the J-point chosen for measurement of ST segment depression (Table 3 and Figure 1), with a specificity of 96% (48/50) in clini-

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**Table 1. Group Characteristics and Exercise Performance**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Clinical normal (n=50)</th>
<th>Clinical angina (n=50)</th>
<th>CAD by catheterization (n=30)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>p*</td>
<td>p†</td>
<td>p‡</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>48±10</td>
<td>62±10</td>
<td>62±10</td>
</tr>
<tr>
<td></td>
<td>&lt;0.001</td>
<td>NS</td>
<td>0.001</td>
</tr>
<tr>
<td>Sex (male/female)</td>
<td>40/10</td>
<td>28/22</td>
<td>25/5</td>
</tr>
<tr>
<td></td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
<td>NS</td>
</tr>
<tr>
<td>Exercise duration (min)</td>
<td>17.5±3.1</td>
<td>12.2±3.5</td>
<td>10.2±3.8</td>
</tr>
<tr>
<td></td>
<td>&lt;0.001</td>
<td>&lt;0.05</td>
<td>0.001</td>
</tr>
<tr>
<td>Proportion of target heart rate achieved (%)</td>
<td>94±7</td>
<td>79±13</td>
<td>68±10</td>
</tr>
<tr>
<td></td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Peak heart rate (beats/min)</td>
<td>165±13</td>
<td>134±23</td>
<td>115±17</td>
</tr>
<tr>
<td></td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Peak systolic blood pressure (mm Hg)</td>
<td>183±17</td>
<td>180±28</td>
<td>160±24</td>
</tr>
<tr>
<td></td>
<td>NS</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Values are mean±SD. CAD, coronary artery disease; NS, not significant.
*Clinical normal group vs. clinical angina group.
†Clinical angina group vs. CAD by catheterization group.
‡CAD by catheterization group vs. clinical normal group.

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**Table 2. Effect of ST Segment Measurement Position on Magnitude of ST Segment Depression at Peak Exercise**

<table>
<thead>
<tr>
<th>ST segment depression (μV)</th>
<th>ST measurement position (msec after J-point)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Clinical normal (n=50)</td>
</tr>
<tr>
<td></td>
<td>p*</td>
</tr>
<tr>
<td>J+0</td>
<td>186±82§</td>
</tr>
<tr>
<td>J+20</td>
<td>119±66§</td>
</tr>
<tr>
<td>J+40</td>
<td>72±60§</td>
</tr>
<tr>
<td>J+60</td>
<td>43±47</td>
</tr>
<tr>
<td>J+80</td>
<td>29±43</td>
</tr>
</tbody>
</table>

Values are mean±SD. CAD, coronary artery disease; NS, not significant.
*Clinical normal group vs. clinical angina group.
†Clinical angina group vs. CAD by catheterization group.
‡CAD by catheterization group vs. clinical normal group.
§p<0.001 vs. J+60 ST measurements in the same group.
cally normal subjects and sensitivity of 59% (47/80) in patients with known or likely coronary disease. Comparison of ROC curves for standard criteria determined using ST depression measured from 0 to 80 msec after the J-point confirmed the similar performance of standard criteria between 20 and 80 msec after the J-point but demonstrated significantly lower performance of standard criteria when ST segment depression was measured at the J-point rather than at 60 msec after the J-point (ROC area, 0.819 versus 0.884, p<0.01) (Figure 2).

In contrast to standard test criteria, sensitivity and test partition values of the absolute magnitude of ST depression (including upsloping as well as horizontal or downsloping ST segments) were significantly affected by the time after the J-point chosen for ST segment measurement (Table 3 and Figure 1). At a matched specificity of 96%, sensitivity of ST depression alone was significantly lower between 0 and 40 msec after the J-point (14–49%) than when ST depression was measured at 60 msec after the J-point (66% [53/80], p<0.001) or when ST depression was measured at 80 msec after the J-point (61% [49/80], p<0.001), with partition values ranging from 320 to 120 μV (Table 3). Comparison of ROC curves for the performance of ST depression confirmed that overall test accuracy for coronary disease was lower when measured at the J-point or 20 msec after the J-point than at 60 msec after the J-point, but it was not significantly different when ST depression was measured at 40 or 80 msec after the J-point (Figure 2).

**Effect of ST Measurement Position on Test Accuracy of the ST/HR Slope and the ΔST/HR Index**

The effects of measuring ST segment depression at varying times after the J-point on test accuracy of the ST/HR slope and the ΔST/HR index for the detection of coronary disease are outlined in Table 3 and Figures 1 and 2. At matched specificity of 96%, a ΔST/HR index partition of 1.41 μV/beats/min derived from ST segment depression measured at 60 msec after the J-point was significantly more sensitive for the detection of coronary disease than a ΔST/HR index partition of 3.60 μV/beats/min at the J-point (90% [72 of 80 patients] versus 64% [51 of 80 patients], p<0.001). ROC curve analysis confirmed...
In contrast, sensitivity of the ΔST/HR index was not significantly degraded by using ST measurements at 20, 40, or 80 msec after the J-point, but a trend was found toward lower test sensitivity at 80 msec after the J-point.

ST/HR slope accuracy appeared to be more dependent than the ΔST/HR index on the time after the J-point at which ST segment depression was measured. In contrast to the 93% (74 of 80 patients) sensitivity of an ST/HR slope partition of 2.08 μV/ beats/min derived from ST segment depression measured at J+60 msec, the ST/HR slope performed poorly when ST depression was measured at the J-point, with a partition of 5.03 μV/ beats/min having a sensitivity of only 61% (49 of 80 patients, p<0.001). At similarly matched specificity, ST/HR slope sensitivity was also significantly lower at both 20 and 80 msec after the J-point. Comparison of ROC curves confirmed that decreased test performance of the ST/HR slope using ST measurements at 0 and at 80 msec after the J-point was independent of partition value selection, and a trend was found toward lower overall performance of the ST/HR slope at 20 msec after the J-point (Figure 2). In the subset of patients with catheterization-proved coronary disease, an ST/HR slope partition of 2.08 μV/ beats/min using ST measurements at 60 msec after the J-point had a sensitivity of 100% (10/10) in patients with one- or two-vessel disease and a sensitivity of 90% (18/20) in patients with three-vessel disease.

**Comparison of Test Performance of Standard and Heart Rate-Adjusted ST Segment Criteria**

Test accuracy of the ST/HR slope and ΔST/HR index are compared with standard exercise test criteria and ST segment depression measured at varied times after the J-point in Table 3 and Figures 1 and 3. At matched specificity of 96%, sensitivity of the ST/HR slope and sensitivity of the ΔST/HR index for the detection of coronary disease were each significantly

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**FIGURE 2.** Graphs showing receiver operating characteristic (ROC) curves comparing overall test performance of the ST segment/heart rate (ST/HR) slope, delta ST/HR index, magnitude of ST segment depression, and standard criteria at times between 0 and 80 msec after the J-point. *p<0.05, **p<0.01, and ***p<0.001 vs. J+60 performance.
higher than the sensitivity of standard criteria or ST depression partitions when ST depression was measured between 20 and 80 msec after the J-point (Table 3 and Figure 1). In contrast, there was no significant difference in test sensitivity of standard criteria (59% [47 of 80 patients]), the ST/HR slope (61% [49 of 80 patients]) and the ΔST/HR index (64% [51 of 80 patients]) when ST segment depression was measured at the J-point. ROC curve analysis confirmed the superior overall test performance of the two heart rate–adjusted indexes of ST segment depression at 20, 40, and 60 msec after the J-point and demonstrated
that the similar test performance of standard criteria and heart rate–adjusted indexes of ST depression at the J-point was not dependent on the choice of test partitions (Figure 3). Of note was the slightly diminished overall test performance of the ST/HR slope (ROC area, 0.895) but not the ΔST/HR index (ROC area, 0.951) at 80 msec after the J-point.

Discussion

These findings demonstrate that use of J-point measurement of ST depression rather than J+60 measurement significantly degrades the performance of both the ΔST/HR index and the ST/HR slope for the detection of coronary artery disease. These data support preliminary observations from our laboratory in a separate population28 and offer additional insight into the potentially adverse effects of methodological variation on the discriminating power of heart rate–adjusted indexes of ST segment depression for the identification of coronary obstruction.10,17-21 In contrast, standard ST segment criteria are not as importantly affected by the time after the J-point at which ST segment depression is measured.

Heart Rate–Adjusted ST Segment Criteria

Most studies demonstrating improved accuracy of the ΔST/HR index or ST/HR slope for the identification of coronary artery disease have measured ST depression at 60–80 msec after the J-point.7,8,10-12,14-17 In contrast, a recent study demonstrating no difference between standard criteria and the ΔST/HR index for the detection of coronary disease used J-point ST depression measurements.21 Although some of the differences in test accuracy between these studies may be explained by differences in the selection of normal subjects for the definition of test specificity,18 an important cause of diminished test performance at the ΔST/HR index is the substitution of J-point depression for ST depression measured at 60–80 msec after the J-point.

An increase in the magnitude of J-point depression during exercise is common in normal subjects who have rapidly upsloping ST segments, but this is less common in patients who have coronary disease.22-25,27,38-41 Because heart rate–adjusted indexes of ST segment depression are calculated independent of the upsloping, horizontal, or downsloping nature of ST depression,10,13,14,17,19,20,33 these methods can be markedly affected by both the time after the J-point at which ST depression is measured and by the prevalence of upsloping ST segment depression in the populations used to define test performance.10,18 Thus, the greater magnitude of ST depression in clinical normals when ST depression is measured at the J-point, together with the relative lack of dependence of the magnitude of ST depression on the time at which ST depression is measured in patients with coronary disease, results in lower test accuracy of both the ΔST/HR index and the ST/HR slope for the detection of coronary obstruction when J-point depression is substituted for ST segment depression measured 60 msec after the J-point (Table 3 and Figures 1 and 2). Interestingly, test performance of both the AST/HR index and the ST/HR slope appear to decrease using measurements made 80 msec after the J-point (Table 3 and Figures 1 and 2). This loss of sensitivity may be due to coincidence of this point with the beginning of the T wave in patients with coronary disease who have slowly upsloping ST depression at peak exercise.10

Standard Exercise Test Criteria

Previous studies21,26 have suggested that standard ST segment depression criteria, which incorporate the magnitude of ST depression only when the ST segment has a horizontal or downward slope, should be independent of the time after the J-point at which ST segment depression is measured. The present study confirms that sensitivity of a partition of 0.1 mV of horizontal or downsloping ST depression is not significantly affected by the position on the ST segment at which ST depression is measured, even though a trend toward lower overall test accuracy is apparent as ST measurement position approaches the J-point. This trend may be explained by the decreasing magnitude of downsloping ST segment depression as measurement approaches the J-point.

Optimal ST Measurement Position

These data and previous findings16,18,27-29 suggest that ST/HR slope and ΔST/HR index accuracy are highest when ST segment depression is measured 60 msec after the J-point. Simoons27 and Simoons and Hugenholtz28 demonstrated superior overall accuracy of ST measurements made 60 msec after the J-point for the identification of coronary disease, particularly when adjusted for the magnitude of ST depression at similar heart rates in normal subjects. Similarly, the discriminant analysis of Detty et al,29 confirmed by Deckers et al,16 demonstrated that ST depression at 60 msec after the J-point was the most potent ST segment descriptor of the presence of coronary disease. Although overall test performance of heart rate–adjusted methods was not statistically different between 40 and 60 msec after the J-point in the present study (Figure 2), there was a clear trend toward higher sensitivity using ST depression measured 60 msec after the J-point at clinically relevant higher specificities (Table 3 and Figures 1 and 2). However, if measurements made at 40 msec after the J-point are used, partition values must be adjusted for the greater magnitude of ST depression found in clinically normal subjects when ST depression is measured at 40 as opposed to 60 msec after the J-point (Tables 2 and 3).

The present study also confirms previous suggestions that standard criteria are less dependent on the time at which ST depression is measured,21 with similar sensitivity found for partitions of 100 μV of horizontal or downsloping ST depression at each ST segment measuring point (Figure 1 and Table 3). However, the superior overall test accuracy by ROC curve analysis of standard criteria using ST depres-
sion measured at 40 or 60 msec after the J-point, particularly at high levels of specificity (Figure 2), suggests that either of these points should be chosen when different amounts of horizontal or downsloping ST depression are used as test criteria.

Methodological Implications

These findings again highlight the often profound effects that seemingly small changes in methodological detail can have on the accuracy of the ΔST/HR index and the ST/HR slope.\textsuperscript{10,17-20} In addition to the effect of ST segment measurement point shown in the present study, differences in selection of test population,\textsuperscript{18,21} in electrocardiographic lead groups,\textsuperscript{19} in exercise protocol,\textsuperscript{19} and in the precision of ST segment measurements\textsuperscript{18} can also affect performance of heart rate–adjusted indexes of ST segment depression. Thus, the highly referred nature of our study groups, with relatively young age of the normal subjects and high prevalence of anatomically extensive disease in the group undergoing angiography, limits to some degree the extent to which test performance of heart rate–adjusted criteria can be generalized to populations with intermediate pretest probabilities of coronary disease. ΔST/HR index and ST/HR slope partitions with 96% specificity in normal subjects in the present study (1.41 and 2.08 μV/beats/min) differ only slightly from partitions with 95% specificity in our previous studies using ST depression measured at 60 msec after the J-point (1.60 and 2.40 μV/beats/min).\textsuperscript{17} However, these previously derived partitions maintained high specificity (each 100%) and high sensitivity (88% and 93%, respectively) in the current population.

References


KEY WORDS • ST segments • exercise electrocardiogram • heart rate • J-point
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