Comparison of ST Segment/Heart Rate Index to Standard ST Criteria for Analysis of Exercise Electrocardiogram

Bruce Lachterman, MD, Kenneth G. Lehmann, MD, Robert Detrano, MD, PhD,
Joel Neutel, MD, and Victor F. Froelicher, MD

The objective of our study was to compare the discriminating power of a proposed ST segment/heart rate index with that of a standard method of assessing exercise-induced ST segment depression for diagnosing coronary artery disease. We used a cross-sectional retrospective analysis of exercise test and coronary angiographic data. The study took place in a 1,200-bed Veterans Affairs Medical Center; participants were 328 male patients who had undergone both a sign and symptom–limited treadmill test and coronary angiography. The sensitivity of the ST segment/heart rate index was 54% at a cut point of 0.021 mm/(beats/min), corresponding to a specificity of 73%. The standard visual ST segment analysis had a sensitivity of 58% at this same specificity, which corresponded to an ST segment cut point of 1-mm depression relative to rest (p=NS). Similarly, for diagnosing three-vessel or left main coronary disease, no significant difference was found between the sensitivities or the two measurements at cut points of equivalent specificity. In this consecutive series of patients presenting for routine clinical testing, the ST segment/heart rate index did not improve the diagnostic accuracy of the exercise test for identifying the presence or severity of coronary artery disease relative to standard visual criteria. (Circulation 1990;82:44–50)

The exercise-induced depression of the ST segment is an accepted sign for predicting the presence of coronary artery disease and an aid for the decision to perform coronary angiography. Several investigators have shown an improvement in the diagnostic accuracy of ST depression by using a variety of heart rate–adjustment schemes. Some of these methods are laborious or require computerization. Some groups, however, have noted superior accuracy by using a simple method of heart rate adjustment. The purpose of this study was to assess this approach for detecting any angiographic coronary disease as well as identifying left main coronary or three-vessel disease.

Methods

Population

In our laboratory, 2,044 patients, approximately 30% of whom had coronary angiography, underwent routine clinical exercise testing from 1985 to 1987.

After excluding women (less than 2% of our population), patients with previous revascularization procedures, and patients with left bundle branch block, 328 patients remained. Most were referred for testing because of chest pain syndromes; the remainder were tested for functional capacity evaluation or miscellaneous other reasons.

Exercise Test

The exercise test was performed by using a standard progressive protocol. All tests were sign and symptom–limited maximal tests using recommended criteria for termination; fatigue or chest pain were the reasons for stopping in the majority. The Borg scale of perceived exertion and systolic blood pressure was recorded for each stage, and METs achieved were estimated from the treadmill speed and grade. The treadmill was stopped abruptly at the completion of exercise, and the patient was placed supine within 1 minute of stopping. Electrocardiographic recording continued for at least 6 minutes into recovery or until electrocardiographic changes stabilized.

Electrocardiographic Measurements

Q waves were considered diagnostic if they occurred in two adjacent leads, and were 40 msec in
duration and 25% in amplitude of the following R wave. The PR segment was considered the isoelectric line, and ST measurements were made at the J-junction. The J-junction was used to avoid overlap with the T wave at high heart rates although we have demonstrated little change in classification between this point and 70 msec later.\textsuperscript{13} If the ST segment level at standing rest was above the isoelectric line (early repolarization), the resting baseline ST segment level was considered zero; if it was below the isoelectric line, the negative value was used. Delta ST (ΔST) was calculated as the resting standing value (determined as previously stated, with early repolarization considered zero) subtracted from the value at maximal exercise without slope considered. Delta heart rate (ΔHR) was calculated as standing preexercise heart rate subtracted from the maximal heart rate value during exercise. All 12 leads were examined with the lead of maximum change used for analysis. The greatest change usually occurred in the lateral precordial leads (V₄, V₅, and V₆). For the standard interpretation, ST segment changes in recovery were included; however, calculation of the maximal ΔST segment value only considered changes occurring during exercise. For standard criteria, the ST segment response was only considered abnormal if it was horizontal or downsloping over the 60 msec after the J-junction.

**Angiography**

Coronary angiograms were performed in the standard manner. Stenoses of at least 75% of the diameter of an adjacent normal arterial segment were considered significant. The number of vessels diseased was calculated as one for the left anterior descending artery, diagonal artery, or both, one for the right coronary artery, and one for the circumflex artery, obtuse marginal artery, or both.

**Data Analysis**

Continuous variables are described as the mean±1 SD. Two-tailed Student’s \( t \) tests were used to compare means of groups for continuous data, and \( \chi^2 \) and McNemar tests were used to compare uncorrelated and correlated properties, respectively. Sensitivities and specificities are given with their 95% confidence intervals.

Receiver operating characteristic (ROC) curves were also computed and compared using the method of Hanley and McNeil.\textsuperscript{14} A probability (\( p \)) value of 0.05 was used as the level of statistical significance.

**Results**

Table 1 describes the clinical characteristics of the study sample grouped by the number of major vessels with significant coronary stenosis. Of the 328 patients, 80 (24%) had no such obstruction, 183 (56%) had one- or two-vessel disease, and 65 (20%) had left main or three-vessel disease, or both. The mean age in the sample was 59 years. Slightly more than half of the patients presented with typical angina pectoris, and approximately 40% of the patients had a history of previous myocardial infarction (MI) or had electrocardiograms (ECGs) with diagnostic Q waves. Medication status during testing was usually not altered from that already prescribed. Thus, 39% of the patients were taking \( \beta \)-blockers and 10% were taking digoxin. For the features listed in Table 1, no significant differences were found between patients with one- or two-vessel disease and those with three-vessel or left main disease; however, the last column of the table
shows most of these features were significantly different for the subjects with no vessel disease versus those patients with any disease.

Myocardial Infarction by History/Q Waves

Table 2 demonstrates the relation between diagnostic Q waves or previous history of MI and the presence of any angiographic coronary disease, or three-vessel or left main disease. Because of silent and non-Q wave MIs and regression of Q waves, the Q wave and MI classifications did not agree completely. The presence of either Q waves or a history of MI, however, similarly increased the probability of any significant coronary artery disease and the probability of three-vessel or left main disease. Because the prevalence of any coronary artery disease was at least 85% in the Q wave/MI groups regardless of the exercise test results, the clinical usefulness of the exercise test in these groups depends on its ability to distinguish severe coronary artery disease (three-vessel or left main disease) from nonsevere coronary artery disease.

Exercise Test Responses

Table 3 describes the exercise test responses of the study sample grouped by the number of vessels with 75% or greater diameter narrowing. The mean maximal heart rate was significantly different between groups and was inversely related to the severity of coronary disease. The age-predicted maximal heart rate for this group was approximately 150 beats/min but the lower mean value achieved is partially explained by clinical indications for stopping the test and the use of β-blockers. The mean maximal Borg scale value of 17 (very hard) is consistent with a near maximal effort; it was 18 in those patients without angina. The peak systolic blood pressure, maximal aerobic capacity estimated in METs, and the difference in the double product from standing rest to

---

### Table 2. Effect of Q Waves and History of Myocardial Infarction on Prevalence of Angiographic Coronary Artery Disease

<table>
<thead>
<tr>
<th></th>
<th>Q waves</th>
<th></th>
<th>History of MI</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>(n=131)</td>
<td>(n=197)</td>
<td></td>
<td>(n=141)</td>
<td>(n=187)</td>
</tr>
<tr>
<td>Any significant disease (%)</td>
<td>115 (88)</td>
<td>133 (68)*</td>
<td>120 (85)</td>
<td>128 (68)*</td>
</tr>
<tr>
<td>Three-vessel or left main disease (%)</td>
<td>34 (26)</td>
<td>31 (16)*</td>
<td>31 (22)</td>
<td>34 (18)</td>
</tr>
</tbody>
</table>

MI, myocardial infarction.

*p<0.01.

(These values are the percentage of patients with abnormal angiographic findings according to Q wave or history of MI.)

---

### Table 3. Exercise Test Results Grouped by Extent of Coronary Artery Disease

<table>
<thead>
<tr>
<th></th>
<th>All patients (n) (%)</th>
<th>Patients without CAD (n) (%)</th>
<th>Patients with CAD (n) (%)</th>
<th>1–2 VD</th>
<th>3 VD/LM</th>
<th>p*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients (n) (%)</td>
<td>328 (100)</td>
<td>80 (24)</td>
<td>248 (76)</td>
<td>183 (56)</td>
<td>65 (20)</td>
<td>...</td>
</tr>
<tr>
<td>Maximal heart rate (beats/min)</td>
<td>126±22</td>
<td>130±24</td>
<td>124±21</td>
<td>125±22</td>
<td>121±20</td>
<td>0.03</td>
</tr>
<tr>
<td>Peak systolic pressure (mm Hg)</td>
<td>161±31</td>
<td>165±33</td>
<td>160±30</td>
<td>163±31</td>
<td>151±27</td>
<td>NS</td>
</tr>
<tr>
<td>Workload (METs)</td>
<td>6.7±2.9</td>
<td>6.9±3.2</td>
<td>6.7±2.9</td>
<td>7±2.8</td>
<td>6±2.6</td>
<td>0.01</td>
</tr>
<tr>
<td>Double product difference [(beats/min) · mm Hg]</td>
<td>10.6±5.2</td>
<td>11.2±5.3</td>
<td>10.4±5.0</td>
<td>11.0±5.1</td>
<td>8.5±0.4</td>
<td>0.001</td>
</tr>
<tr>
<td>Perceived exertion (Borg scale)</td>
<td>17±2.8</td>
<td>17±2.8</td>
<td>17±2.8</td>
<td>17±2.6</td>
<td>17±3.2</td>
<td>NS</td>
</tr>
<tr>
<td>With angina during test (n) (%)</td>
<td>115 (35)</td>
<td>14 (17)</td>
<td>101 (41)</td>
<td>74 (40)</td>
<td>27 (42)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Abnormal by standard ST criteria (n) (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;1 mm</td>
<td>168 (51)</td>
<td>22 (28)</td>
<td>146 (59)</td>
<td>98 (54)</td>
<td>48 (74)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>&gt;2 mm</td>
<td>98 (30)</td>
<td>10 (13)</td>
<td>88 (36)</td>
<td>50 (27)</td>
<td>38 (59)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>With downsloping ST–exercise (n) (%)</td>
<td>69 (21)</td>
<td>9 (11)</td>
<td>60 (24)</td>
<td>33 (18)</td>
<td>27 (42)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>With downsloping ST–recovery (n) (%)</td>
<td>116 (35)</td>
<td>9 (11)</td>
<td>107 (43)</td>
<td>66 (36)</td>
<td>41 (63)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>ΔST (mm)</td>
<td>1.2±1.2</td>
<td>0.6±0.9</td>
<td>1.3±1.3</td>
<td>1.1±1.4</td>
<td>1.9±1.5</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>ST/HR index (uV/beat/min)</td>
<td>2.6±3.3</td>
<td>1.4±2.1</td>
<td>3.0±3.5</td>
<td>2.5±3.3</td>
<td>4.4±3.6</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Abnormal by ST/HR criteria (n) (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;1.6 uV/beat/min</td>
<td>174 (53)</td>
<td>26 (32)</td>
<td>148 (60)</td>
<td>102 (56)</td>
<td>46 (71)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>&gt;3.2 uV/beat/min</td>
<td>101 (31)</td>
<td>11 (14)</td>
<td>90 (36)</td>
<td>52 (28)</td>
<td>38 (59)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

CAD, coronary artery disease; 1–2 VD, single- or double-vessel disease; 3VD/LM, three-vessel or left main coronary artery disease; Double product difference, difference in heart rate–systolic pressure product between baseline and maximal exercise; ΔST, change in ST segment depression from baseline to maximal exercise; HR, heart rate.

*Statistical significance (p) for comparison of patient groups using analysis of variance.
maximal exercise were significantly lower in those with left main or three-vessel disease.

**ST Segment Responses and the Prediction of any Significant Coronary Disease**

ST elevation occurred during exercise in 17 patients, all of whom had Q waves, a previous MI, or both, and was accompanied by abnormal depression in other leads in seven patients. To compare the discriminating power of the two types of measurements, a clinically relevant cut-point value of 1-mm ST segment depression was chosen to compare sensitivities at the same specificity. The specificity of the standard criteria of this cut point was 73% (95% confidence interval (CI), 63–82). The sensitivity of this cut point was 58% (95% CI, 52–64). The ST/heart rate index required a cut point of 2.1 uV/(beats/min) to achieve the same specificity of 73%. Its sensitivity at this cut point was only 54% (95% confidence limit, 48–60), 4% lower than the standard criterion (p=NS). This calculation was repeated for the 197 subjects without significant Q waves on their resting ECGs. The specificity of 1-mm depression of the standardized criterion was identical, that is, 73% (95% confidence limit, 60–81). The sensitivity, however, was higher, that is, 69% (95% confidence limit, 60–76). For the ST/heart rate index cut point of 2.3 uV/beats/min corresponding to the same specificity of 73%, the sensitivity was significantly less, that is, 56% (95% confidence limit, 47–64) (p=0.01). ROC curves for all subjects and for those without Q wave infarction are displayed in Figures 1 and 2. There was no significant difference between the areas under these curves.

**Identification of Three-Vessel Disease, Left Main Disease, or Both**

The sensitivity at equivalent specificity for triple-vessel or left main disease was also calculated for both types of measurement. The specificity used in this instance (that corresponding to 1-mm ST segment depression by the standard measurement) was 55% (95% confidence limit, 49–61). The sensitivities at this specificity for the two measurements were 74% (95% confidence limit, 62–83) and 71% (95% confidence limit, 59–80) for the conventional measurement and the ST heart rate index, respectively. McNemar’s test showed no significant difference between these two sensitivities. The ROC curves for these measurements were calculated and are displayed in Figure 3.

**Discussion**

Table 4 is a summary of investigations assessing adjustment of ST segment depressions for heart rate. The sensitivities and specificities listed in the table are for the prediction of any significant angiographic obstruction. All the investigations tabulated (with the exception of the present investigation) have shown a significant increase in accuracy by application of heart rate adjustment. Results closest to those of the present report (demonstrating only modestly increased accuracy) were achieved by Detrano and colleagues in a group of 303 patients at the Cleveland Clinic. They found an increase in sensitivity of 4% at a fixed specificity of 73%, corresponding to an exercise-induced ST segment depression of 1 mm. On the other hand, Kligfield and colleagues found a very large increase in sensitivity, from 68% to 91%, with a smaller increase in specificity from 83% to 93%. The results of the other investigators fall between these two extremes. Methodological differences between the study designs might explain some of these differences. First, some investigators have used a greater-than-50% rather than a greater-than-75% luminal diameter narrowing to define significant angiographic disease. A glance at the table, however, reveals that this could hardly explain a large part of the variability in the resulting sensitivities and specificities. Furthermore, our recent meta-analysis of the exercise electrocardiographic literature showed no relation between the definition of angiographic narrowing and the variance in sensitivity and specificity.

Another possible explanation of the differing results is the different method of measuring heart rate–adjusted ST segment depression. In Table 4, the names of authors marked by asterisks indicate the investigators who used the same method of calculating heart rate–adjusted ST depression as used in the
current investigation. That is, the difference between ST segment depression at peak exercise and ST segment depression at rest is divided by the exercise-induced increase in heart rate. Note that Kligfield et al also used this method in the report listed in Table 4. The reports lacking asterisks indicate the use of the ST segment/heart rate maximum-slope method first introduced by Elamin et al. This can be done, as Elamin did, by using a magnifying glass and carefully plotting ST segment changes against heart rate, or it can be done with a computer. Manual performance of these calculations takes several hours per test and is therefore not applicable to busy exercise labs. Computer algorithms have been prepared, which rapidly perform these calculations. These algorithms, however, are subject to the vagaries and inconsistencies that we have seen in other computerized measurement strategies. Furthermore, Kligfield et al have shown only an insignificant difference between the results of the ST segment/heart rate slope method of Elamin et al and the ST segment/heart rate index method used in their most recent work and in the present report.

Differences in the application of the conventional criterion could certainly affect the differences between the accuracies of the two methods. Specifically, the treatment of ST segment slope has potential importance. In our recent meta-analysis, the treatment of slope was one of the few technical variables that significantly affected the accuracy of the exercise–ST segment depressions. In the present investigation, only exercise-induced depression of the J-point was measured, and this was assigned the value 0 when ST segment slope was upsloping. The effect of this on test accuracy can be seen by studying the ROC curve for the initial criteria in Figure 2. Note that the curve for the conventional ST segment depression has a rather sharp “bump” at the point corresponding to 1-mm ST depression (at a false-positive rate of 0.27 and a sensitivity of 0.66). If the slope itself is ignored, this bump will disappear and the false-positive rate of 1-mm ST segment depression will increase at the same sensitivity. This effect, however, appears small. Furthermore, the other investigators listed in the table had different approaches toward slope, which did not negate the increased accuracy of heart rate–adjusted ST depressions. Noteworthy, however, is that Detrano et al looked at the effect of slope separately. Although their treatment of slope was slightly different than ours, their method also treated upsloping depression conservatively. When this was done, no difference was noted between sensitivities of the conventional method and sensitivities of the heart rate–adjusted ST segment depressions at the same specificity of 73%. We conclude that our treatment of slope explains some of the difference between our results and those of the investigators listed in Table 4.
Aside from the technical issues previously discussed, patient population differences might explain differences in reported accuracies. As Table 4 shows, four of the seven previous reports included only patients undergoing cardiac catheterization. Three of the reports, including that of Kligfield et al., included so-called “normal” controls. These are usually chosen as a group of individuals with very low probability of coronary artery disease. Because these subjects’ probability of coronary artery disease is very low, the authors assumed that an abnormal exercise–ST segment depression is a false-positive and can be discounted. The use of normal controls usually has a practical as well as a theoretical justification. The practical justification is the lack of sufficient numbers of catheterized patients who do not have a significant coronary artery obstruction. Lacking sufficient numbers, an investigator cannot have confidence in the calculated test specificity without turning to another group of “normal subjects.” The theoretical justification is that patients with normal coronary angiograms will produce an inordinate number of false-positive results because of workup or referral bias. We argue to the contrary, that is, if a subject’s probability of coronary artery disease is so low that, no matter how abnormal his exercise test result, he is still assumed not to have disease, he and his test results are of no interest to the clinical users of exercise testing. He is among the “wellest of the well” and should not be used in comparing various protocols and exercise variables. In our estimation, it is a less serious error to use normal angiogram control subjects, for whom a more accurate exercise test might have precluded the angiogram, than to use control subjects who would never be considered for angiography or exercise testing. It is noteworthy that in the three reports in Table 4 using normal controls, there were large differences in the accuracies of the two methods. We believe that this difference in control group is responsible for some of the differences between our results and those of some investigators listed in Table 4. We have reviewed the data of Decker et al. and found that when the patients not undergoing coronary angiography are excluded, the increase in accuracy caused by heart rate adjustment decreases, thus supporting our contention.

Another difference in the analysis relative to population issues between our studies is that Kligfield et al. included patients with previous MIs but did not consider the test performance with and without them separately, as we did. Diagnosis of coronary disease is not usually an issue in patients with previous MIs because they are very likely to have disease.

Another methodological factor that could result in an apparent increase in accuracy is the treatment of equivocal results when using the standard criterion. We have found that bias resulting from this factor can significantly affect the reputed accuracy of exercise testing. An example of such bias is illustrated in the report of Kligfield et al.

These investigators excluded equivocals (17% of study group) from the numerators for the calculation of sensitivity and specificity. In an overview of 147 publications, we found this treatment of equivocal results used only one time. Such a biased treatment of equivocals falsely improves both sensitivity and specificity. The test results so assigned and therefore excluded involved upsloping ST segments. These should be treated as normal as we have done in the present investigation. It can be deduced from the report of Kligfield et al. that the specificity of the standard criterion would have been similar to that of the heart rate–adjusted method if these authors had treated equivocals in a conventional manner.

Another difference between the studies is that Kligfield et al. did not consider recovery changes, as we did. We have found recovery measurements to increase sensitivity without a decrease in predictive value.

**Limitation of Present Study**

Meticulous review of the exercise electrocardiographic literature has taught us the difficulties inherent in studying the factors affecting sensitivity and specificity of the exercise ST segment. Reports commonly suffer from methodological bias and miss-

---

**TABLE 4. Sensitivities and Specificities Reported in Literature for Heart Rate-Adjusted Versus Nonadjusted ST Depression**

<table>
<thead>
<tr>
<th>Author (yr)</th>
<th>Subjects (n)</th>
<th>Conventional criteria</th>
<th>Heart rate–adjusted criteria</th>
<th>Only patients with cardiac cath</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simoons (1977)</td>
<td>138</td>
<td>95 (82/86)</td>
<td>93 (80/86)</td>
<td>No</td>
</tr>
<tr>
<td>Elamin (1986)</td>
<td>206</td>
<td>88 (15/17)</td>
<td>100 (138/138)</td>
<td>Yes</td>
</tr>
<tr>
<td>Detrano (1986)</td>
<td>303</td>
<td>73 (120/164)</td>
<td>73 (120/164)</td>
<td>Yes</td>
</tr>
<tr>
<td>Finkelhor (1986)</td>
<td>64</td>
<td>78 (24/27)</td>
<td>89 (24/27)</td>
<td>Yes</td>
</tr>
<tr>
<td>Deckers (1988)</td>
<td>345</td>
<td>90 (158/175)</td>
<td>90 (158/175)</td>
<td>No</td>
</tr>
<tr>
<td>Kligfield (1989)</td>
<td>300</td>
<td>83 (125/150)</td>
<td>93 (139/150)</td>
<td>No</td>
</tr>
<tr>
<td>Sato (1989)</td>
<td>142</td>
<td>76 (25/33)</td>
<td>97 (29/30)</td>
<td>Yes</td>
</tr>
<tr>
<td>This report*</td>
<td>328</td>
<td>73 (58/80)</td>
<td>73 (58/80)</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Sensitivity and specificity values represent percentages, with values in parentheses indicating number of patients. % Diameter narrowing, criterion for significant coronary artery disease; cath, catheter.

*ST segment/heart rate adjustment done by dividing the differences in the ST segment level at peak exercise and at rest by the difference between the peak heart rate and the resting heart rate.
ing data. Different populations respond differently to the stress of exercise, and measurement error also introduces noise into reported results. In the present report, we have tried to avoid bias and include detailed information concerning our population and methods. Still, ours, like most similar studies, is retrospective with all the inherent problems. Moreover, our population (male veterans with high-disease prevalence) is not representative of the population as a whole. We await the publication of reports on large multicenter databases that can more clearly explain the factors affecting the accuracy of various methods of analysis.

Acknowledgments

Thanks to Lesley Anderson for typing and to Margo Hullett for performing the tests.

References


Key Words • exercise testing • coronary angiography • heart rate • ST segment depression
Comparison of ST segment/heart rate index to standard ST criteria for analysis of exercise electrocardiogram.
B Lachterman, K G Lehmann, R Detrano, J Neutel and V F Froelicher

Circulation. 1990;82:44-50
doi: 10.1161/01.CIR.82.1.44

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1990 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/82/1/44

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

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

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