ST Segment Tracking for Rapid Determination of Patency of the Infarct-Related Artery in Acute Myocardial Infarction

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Objectives. This study was designed to test the hypothesis that monitoring the ST segment on a single electrocardiographic (ECG) lead reflecting activity in the infarct zone provides sensitive and specific recognition of reperfusion within 60 min of initiation of therapy in acute myocardial infarction.

Background. Infarct-related arteries that fail to recanalize early may benefit from immediate rescue angioplasty. Hence, detection of reperfusion has important practical clinical implications.

Methods. Of 41 patients with acute myocardial infarction who had ambulatory ECG (Holter) monitors placed, 38 had adequate ST segment monitoring for 3 h; 35 of the 38 were treated with thrombolytic agents and 3 with primary angioplasty. All patients underwent early coronary angiography and were classified into two groups: Group P (22 patients) had angiographic patency (Thrombolysis in Myocardial Infarction [TIMI] grade 2 or 3 flow), and Group O (16 patients) had persistent occlusion (TIMI grade 0 or 1 flow) of the infarct-related vessel at 60 min from initiation of therapy. The initial ST segment level was defined as the first ST segment level recorded; the peak ST segment level was defined as the highest ST segment level measured during the 1st 60 min. To assess the optimal ST segment recovery criteria for reperfusion, the presence or absence of a ≥75%, ≥50% and ≥25% decrement from initial and peak ST segment levels, sampled and analyzed at 2.5, 5, 10-, 15-, and 20-min intervals, was correlated with patency of the infarct-related artery at 60 min.

Results. ST segment recovery of ≥50% reduction from peak ST segment levels with sampling rates at ≤10-min intervals provided the optimal criterion for recognizing coronary artery patency at 60 min (sensitivity 96%, 95% confidence interval [CI] 77% to 99%; specificity 94%, 95% CI 69% to 99%, p < 0.00001). The subgroup of 13 patients in Group P with TIMI grade 3 reperfusion flow all met this criterion (sensitivity 100%, 95% CI 75% to 100%). The use of the initial ST segment level as the baseline for determining the presence of a ≥50% reduction in ST segment levels within 60 min was less sensitive. Prediction of coronary reperfusion within 60 min of therapy on the basis of a ≥75% decrement from peak ST segment levels was less sensitive, and the use of a ≥25% decrement was less specific.

Conclusions. ST segment monitoring of a single lead reflecting the infarct zone provides a reliable method for assessing reperfusion within 60 min of acute myocardial infarction. Optimal criteria for ECG reperfusion include a ≥50% decrease from peak ST segment levels, with ST segment measurements recorded continuously or at least every 10 min.

(J Am Coll Cardiol 1995;26:675-83)

The prompt restoration of coronary artery patency in acute myocardial infarction has been linked to a marked improvement in survival (1-4). However, in 15% to 25% of patients treated with thrombolytic agents, the infarct-related artery fails to recanalize, and further interventions such as immediate rescue angioplasty may be of benefit (5-7). Unfortunately, the methods available for rapid and accurate detection of failed thrombolysis are limited. Assessment of clinical variables can be used but is imperfect. Early coronary angiography is accurate but costly, is unavailable in many hospitals and may lead to complications. In addition, it does not provide continuous assessment of the dynamic changes in perfusion that occur after thrombolysis (8). Hence, there is a need for simple, noninvasive markers that promptly identify failed reperfusion and continuously monitor the patency of the infarct-related vessel.

The role of the electrocardiogram (ECG) in the recognition of successful thrombolysis in acute myocardial infarction is controversial. Previous studies (9-21) have reported diverging data on the value of ST segment monitoring in predicting coronary artery patency. Possible explanations for these diverging results include the use of the initial ST segment level as the baseline for measuring changes reflecting reperfusion, a lack of uniform ECG criteria of reperfusion, variable sampling rates for ST segment level measurements and lack of angiographic correlation at the time of ECG analysis. The aim of the present study was to define the optimal methodology, verified by coronary angiography, for the accurate identification of
reperfusion within 60 min of initiation of treatment in acute myocardial infarction. The study was designed to test the hypothesis that continuous ST segment monitoring of a single selected lead and a specific ECG criterion for reperfusion—namely, a ≥50% reduction from the peak ST segment level—provides a sensitive and specific marker of the time of reperfusion. The rationale for tracking ST segment deviations from the peak ST segment level is based on the observation that ST segment fluctuations are unstable during the evolution of acute myocardial infarction and, therefore, the initial ST level is an unreliable baseline (8). The feasibility of the study derived from our participation in the Thrombolysis in Myocardial Infarction (TIMI)-4 thrombolytic trial (22), which provided the justification for acute angiographic assessment of the perfusion status of the infarct-related artery. The data demonstrate the validity of the method tested, as well as some limitations, based on the ECG response to ischemia and reperfusion.

Methods


equation selection. Forty-one consecutive patients admitted to the University of Miami/Jackson Memorial Hospital were prospectively enrolled in a study of continuous ST segment monitoring during treatment of acute myocardial infarction. Thirty-eight patients were enrolled in the TIMI-4 thrombolytic trial (22) and 3 patients were treated with primary angioplasty because of contraindications to thrombolytic therapy. Patients were included if they had symptoms of myocardial ischemia lasting ≥30 min and ≤6 h, and ST segment elevation ≥1 mm in at least two contiguous ECG leads. Exclusion criteria included age >79 years and the presence of left bundle branch block on the admission ECG. The study was approved by the Institutional Review Board of the University of Miami School of Medicine and all patients gave written informed consent.

Thrombolytic protocol. Patients eligible for thrombolytic therapy were randomized in the TIMI-4 protocol to one of the following regimens: 1) accelerated alteplase (Activase), in a bolus dose of 15 mg followed by 0.75 mg/kg body weight over a 30-min period, not to exceed 50 mg, and 0.5 mg/kg, up to 35 mg, over the next 60 min; 2) anistreplase (Eminase), 30 U over 2 to 5 min; or 3) the combination of Eminase, 20 U bolus over 2 to 5 min, and Activase, 15 mg bolus followed by 0.75 mg/kg up to 50 mg over 30 min. All patients were given oral aspirin, 325 mg, and intravenous heparin. Intravenous metoprolol (15 mg divided over three doses) was administered unless its use was contraindicated.

Invasive protocol. All patients underwent early cardiac catheterization. The time of initiation of therapy was defined as the time of administration of thrombolytic therapy or 60 min before balloon inflation in those undergoing primary angioplasty. All times were measured from the time of initiation of therapy. Coronary angiography was performed within 60 min in all patients, and serial angiograms of the infarct-related vessel were obtained at 15-min intervals thereafter to a maximum of 120 min. The TIMI criteria (23) were used for grading the perfusion of the infarct-related artery. Patency was defined as TIMI grade 2 or 3 flow. Infarct-related arteries with TIMI grade 0 or 1 flow were considered occluded. Infarct-related vessels with angiographic occlusion >90 min from the onset of thrombolytic therapy were considered for rescue angioplasty. Patients with contraindications to thrombolytic therapy underwent primary angioplasty immediately after coronary angiography. Coronary angiograms were reviewed at separate research sites (Beth Israel Hospital, Boston, Massachusetts and University of Miami, Miami, Florida) by independent observers who had no knowledge of the ECG data, to control for interobserver variability in the assessment of infarct-vessel perfusion.

Duration of chest pain. All patients were asked at 10- to 15-min intervals, by a research nurse who had no knowledge of the ECG data, to report the presence or absence of chest pain. The time from initiation of therapy to resolution of chest pain was correlated with the angiographic patency of the infarct-related vessel at 60 min.

ST segment monitoring. Ambulatory ECG (Holter) monitors with three channels were placed on all patients within ±10 min of initiation of therapy, and continuous ST segment monitoring was performed. The bipolar leads were positioned to monitor the anterior, inferior or lateral wall according to the infarct site as determined from the 12-lead ECG, and the lead exhibiting the maximal ST segment elevation was chosen for ST segment measurements. All recordings were calibrated and analyzed on a digitized, computer system (Zymed 1610). The frequency response of the recording system for ST segment measurements met the recommendations of the American Heart Association (24). The isoelectric point was set as the preceding PR segment. Computer-derived and manually-verified ST segment measurements were obtained 80 ms after the J point every 2.5 min for 3 h and the mean ST segment level of five complexes was recorded. Ventricular ectopic beats were excluded from analysis. The initial ST segment level was defined as the first ST segment level (mm) recorded; the peak ST segment level was defined as the highest ST segment elevation (mm) measured in the 1st 60 min. To assess the optimal criteria for diagnosing reperfusion, a ≥75%, ≥50% and ≥25% decrement from initial and peak ST segment levels within 60 min of initiation of therapy, ST recovery was correlated with patency of the infarct-related artery at 60 min. The time to ST recovery was defined as the time at which the percent ST change criterion was met with the qualification that the ST segment levels did not increase by >10% in the ensuing 10 min. ST level sampling rates (2.5-, 5-, 10-, 15- and 20-min intervals) were analyzed to determine the minimal frequency of ST segment sampling required for prompt recognition of coronary reperfusion.

Statistical analysis. Data are expressed as mean value ± SD. Statistical analysis was performed with commercially available software (Graphpad-Instat). Differences between groups were examined by Student unpaired t test. The 95% confidence intervals (CI) for proportions were calculated by standard methods. Inter- and intraobserver variabilities were analyzed by paired Student t test. The Fisher exact test was used to test
Table 1. Baseline Clinical Features of Patients With Patent (Group P) and Occluded (Group O) Infarct-Related Arteries at 60 Minutes From Initiation of Therapy

<table>
<thead>
<tr>
<th></th>
<th>Group P</th>
<th>Group O</th>
<th>p Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>(n = 22)</td>
<td>(n = 16)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (yr)</td>
<td>58 ± 13</td>
<td>57 ± 10</td>
<td>0.7788</td>
</tr>
<tr>
<td>Previous MI</td>
<td>14%</td>
<td>19%</td>
<td>0.9999</td>
</tr>
<tr>
<td>Anterior MI</td>
<td>50%</td>
<td>62%</td>
<td>0.5204</td>
</tr>
<tr>
<td>Single-vessel disease</td>
<td>64%</td>
<td>38%</td>
<td>0.1881</td>
</tr>
</tbody>
</table>

*p < 0.05 considered significant. Data are expressed as mean value ± SD or percent of group. MI = myocardial infarction.

Results

Clinical data. Forty-one consecutive patients with acute myocardial infarction were evaluated. Adequate ECG analysis was achieved in 38 patients (93%); 3 patients were excluded because of technical failure of the recorder, incorrect placement of leads or frequent ventricular ectopic impulses. Times to ST recovery were measured in all patients by two independent reviewers; there were no significant inter- or intraobserver differences. All patients underwent cardiac catheterization immediately after initiation of therapy; angiography of the infarct-related vessel was achieved at <40 min in 13 patients, at 45 to 55 min in 7 and at 60 min in 18. The infarct-related artery was the left anterior descending coronary artery in 21 patients (55%), the right coronary artery in 12 (32%) and the left circumflex coronary artery in 5 (13%). Patients were classified into two groups: Group P consisted of 22 patients with angiographic patency of the infarct-related artery at 60 min; 13 of these had TIMI 3 grade flow and 9 had TIMI 2 grade flow. Group O included 16 patients with an occluded artery (TIMI grade 0 or 1 flow) at 60 min. Baseline characteristics were comparable in the two groups (Table 1). There were no significant inter- or intraobserver differences in the assessment of angiographic patency.

Resolution of chest pain. The duration of chest pain before the initiation of therapy (Table 2) was similar in both groups (144 ± 71 min in Group P, 168 ± 85 min in Group O, p = 0.544). Overall, the time from initiation of therapy to resolution of symptoms was shorter in Group P (44 ± 24 min) than in Group O (85 ± 30 min, p = 0.0002). Prediction of angiographic patency (TIMI grade 2 or 3 flow) of the infarct-related vessel, based on the presence or absence of chest pain at 60 min (Table 3), had only limited power (sensitivity 77% [95% CI 54% to 92%; specificity 60% [95% CI 38% to 83%], p = 0.038).

ST segment data. No significant differences were found between Groups P and O in mean initial and mean peak ST segment levels (Table 2). The mean peak ST segment level for all patients studied was significantly higher (5.4 ± 2.5 mm) than the mean initial ST level (3.7 ± 1.8 mm, p = 0.0015). Among 16 patients (42%) who had initial ST segment levels ≤3 mm (mean 2.0 ± 0.7 mm), all had further increments in ST segment levels during the 1st 60 min (mean peak ST = 3.6 ± 1.3 mm, p = 0.0001). Mean ST segment levels at 60 min were significantly lower in Group P (1.4 ± 1.6 mm) than in Group O (4.0 ± 2.1 mm, p = 0.0001). Moreover, within Group P there was a highly significant difference between those with TIMI grade 3 versus TIMI grade 2 flow (0.96 ± 0.67 mm vs. 3.1 ± 2.1 mm, p = 0.0008). The mean ST segment at 60 min in patients with TIMI grade 2 flow was not significantly different from that with TIMI grade 3 or TIMI grade 2 flow (0.96 ± 0.67 mm vs. 3.1 ± 2.1 mm, p = 0.0001).

Table 2. Salient Features of Patients With Patent (Group P) and Occluded (Group O) Infarct-Related Arteries at 60 Minutes From Initiation of Therapy

<table>
<thead>
<tr>
<th>ST segment levels (mm)</th>
<th>Group P (n = 22)</th>
<th>Group O (n = 16)</th>
<th>p Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>3.2 ± 1.7</td>
<td>2.8 ± 1.3</td>
<td>4.0 ± 1.9</td>
</tr>
<tr>
<td>Peak</td>
<td>5.5 ± 2.6</td>
<td>4.8 ± 2.8</td>
<td>6.2 ± 2.4</td>
</tr>
<tr>
<td>At 60 min</td>
<td>1.4 ± 1.6</td>
<td>0.96 ± 0.67</td>
<td>3.1 ± 2.1</td>
</tr>
<tr>
<td>At 180 min</td>
<td>0.98 ± 1.1</td>
<td>0.98 ± 1.2</td>
<td>1.2 ± 0.68</td>
</tr>
<tr>
<td>Time (min)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>From symptom onset to start of therapy</td>
<td>144 ± 71</td>
<td>136 ± 65</td>
<td>156 ± 81</td>
</tr>
<tr>
<td>From start of therapy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>To resolution of symptoms</td>
<td>44 ± 24</td>
<td>44 ± 22</td>
<td>47 ± 28</td>
</tr>
<tr>
<td>To peak ST segment levels</td>
<td>21 ± 14</td>
<td>19 ± 13</td>
<td>25 ± 15</td>
</tr>
<tr>
<td>To ≥50% decrease from initial ST segment levels</td>
<td>65 ± 39</td>
<td>39 ± 19</td>
<td>94 ± 39</td>
</tr>
<tr>
<td>To ≥50% decrease from peak ST segment levels</td>
<td>40 ± 20</td>
<td>30 ± 15</td>
<td>55 ± 15</td>
</tr>
<tr>
<td>From peak ST segment level to its 50% level</td>
<td>21 ± 16</td>
<td>13 ± 7.7</td>
<td>35 ± 15</td>
</tr>
<tr>
<td>Rate of decline from peak ST segment level to its 50% level (mm/min)</td>
<td>-0.21 ± 0.11</td>
<td>-0.28 ± 0.14</td>
<td>-0.12 ± 0.06</td>
</tr>
</tbody>
</table>

*p value comparing Groups P and O. †p < 0.05 comparing patients with Thrombolysis in Myocardial Infarction (TIMI) flow grades 2 and 3 at 60 min from initiation of therapy in Group P. Data are expressed as mean value ± SD. Initial ST segment level = level of the first ST segment recorded; Peak ST segment level = the highest ST segment level measured in the 1st 60 min.
Resolution of chest pain

<table>
<thead>
<tr>
<th>Group</th>
<th>Timi 2 or 3 (n=22)</th>
<th>Timi 3 (n=13)</th>
<th>Group O (n=16)</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Positive (%)</th>
<th>Negative (%)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>From initial ST segment level</td>
<td>17 (54-92)</td>
<td>60 (38-83)</td>
<td>74 (51-89)</td>
<td>66 (38-88)</td>
<td>0.0379</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;50% decrease in ST segment level</td>
<td>14 (40-82)</td>
<td>100 (79-100)</td>
<td>100 (76-100)</td>
<td>67 (44-84)</td>
<td>0.00008</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>From peak ST segment level</td>
<td>21 (77-99)</td>
<td>94 (69-99)</td>
<td>96 (77-99)</td>
<td>94 (69-99)</td>
<td>&lt;0.00001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;75% decrease in ST segment level</td>
<td>9 (20-63)</td>
<td>100 (79-100)</td>
<td>100 (66-100)</td>
<td>55 (35-73)</td>
<td>0.00486</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>From peak ST segment level</td>
<td>12 (54-72)</td>
<td>94 (69-99)</td>
<td>93 (66-99)</td>
<td>100 (76-100)</td>
<td>&lt;0.00001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;25% decrease in ST segment level</td>
<td>19 (65-97)</td>
<td>62 (35-84)</td>
<td>76 (54-90)</td>
<td>77 (46-94)</td>
<td>0.00256</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>From peak ST segment level</td>
<td>22 (84-100)</td>
<td>44 (19-70)</td>
<td>71 (51-85)</td>
<td>100 (59-100)</td>
<td>0.00091</td>
<td></td>
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</tbody>
</table>

For selected markers, data for patients who achieved Timi grade 2 or 3 flow and Timi grade 3 flow are compared with data in Group O. The 95% confidence intervals are in parentheses. Unless otherwise indicated, data are expressed as number of patients. Abbreviations as in Table 2.

from that in patients with Timi grade 0 or 1 flow, p = 0.5253.

Times of initiation of therapy to peak ST segment elevation were not significantly different between Groups P and O (21 ± 14 vs. 30 ± 22 min, p = 0.132).

ST segment recovery measured from initial and peak ST segment levels. Prediction of coronary artery patency within 60 min of initiation of therapy, based on the presence of ST recovery, varied with the ST level measured (initial vs. peak), frequency of ST segment sampling and the grade of Timi reperfusion (Fig. 1 to 5). The time required to reach ST segment recovery criteria for reperfusion in patients with angiographically documented coronary artery patency at 60 min (Group P) differed between measurements obtained from the initial versus the peak ST segment level (Fig. 1A). A 50% decrease in ST segment levels occurred an average of 25 min earlier when measured from the peak ST segment level (mean 40 ± 20 min) than when measured from the initial ST level (mean 65 ± 39 min, p = 0.02) (Table 2), largely because of the rapid decline from the peak ST segment elevation. The rapid fall from peak ST segment elevation in patients in Group P (time from peak ST to 50% decrease from the peak 21 ± 16 min) permitted accurate detection of coronary reperfusion within 60 min of initiation of therapy (Fig. 5). Twenty-one of the 22 patients in Group P (Fig. 2) achieved a >50% decrease in peak ST segment levels by 60 min (96% sensitivity [95% CI 77% to 99%]). In contrast, only 14 of the 22 patients in this group developed a >50% decrease from the initial ST segment level within 60 min of the start of therapy (sensitivity 64% [95% CI 40% to 82%]) (Table 3). The recognition of persistent occlusion of the infarct-related artery at 60 min (Group O) (Fig. 1B) was highly specific based on the absence of a >50% reduction in either the initial or the peak ST level at 60 min (specificity 94% to 100%) (Table 2).

Grade of Timi reperfusion and rate of ST segment decrease. Comparison of various indexes of ST segment resolution in those with Timi grade 3 versus Timi grade 2 flow showed marked differences (Table 2). The time elapsed from peak ST to a 50% decrement of this level was much briefer in those with Timi grade 3 flow at 60 min (mean time 13 ± 7.7 min) than in those with Timi grade 2 flow (mean time 35 ± 15 min, p = 0.001). Furthermore, the rate of ST segment decline from peak ST to its 50% level was significantly steeper for those with Timi grade 3 than for those with Timi grade 2 reperfusion (<0.28 ± 0.14 mm/min vs. <0.12 ± 0.06 mm/min, respectively, p = 0.004). This brisk decline in ST segment elevation in patients with Timi grade 3 reperfusion (Fig. 3) allowed accurate recognition of infarct-related vessel patency at 60 min in this group when a >50% reduction from either peak ST segment levels (sensitivity 100%) or initial ST levels (sensitivity 92%) was used.

Percent decrease in ST segment levels. Defining ST recovery as a >50% reduction in peak ST segment levels led to optimal sensitivity and specificity of the test (Table 3). In contrast, prediction of patency of the infarct-related artery at 60 min based on a >75% reduction in peak ST levels within 60 min of initiation of therapy was less sensitive (54% [95% CI 32% to 75%]; ST segment analysis based on a >25% reduction of peak ST levels within 60 min had a lower specificity of 44%.

Frequency of ST segment monitoring. The frequency of ST level sampling was an important determinant of the predictive power of ST segment monitoring for determining patency of the infarct-related artery (Fig. 4). However, ST segment monitoring reliably predicted infarct vessel occlusion at 60 min, regardless of the frequency of ST segment level measurements (specificity 87% to 100%).
Figure 1. Mean percent ST deviation with 95% confidence intervals (vertical bars) from initial and peak ST segment levels versus time from initiation of therapy. A, Patients with angiographic coronary artery patency at 60 min (Group P). B, Patients with angiographic coronary artery occlusion at 60 min (Group O). In patients in Group P a 50% reduction in ST segment levels occurs 25 min earlier when values are measured from peak rather than initial ST segment levels. Ambulatory electrocardiographic (Holter) monitors were placed within ±10 min of initiation of therapy; therefore, ST deviation at 0 min is not precisely zero in all cases.

**Evaluation of ST recovery at 60 versus 90 min.** Among the 38 patients, 16 (Group O) had angiographic occlusion of the infarct-related artery at 60 min; excluding 1 patient who underwent primary angioplasty, only 4 others (27%) had reperfusion without mechanical intervention between 60 and 90 min. Thus, 73% of this group had failed reperfusion by

Figure 2. Plot of time (in minutes) to reach a ≥50% reduction from peak ST segment levels (Time to ST Recovery) versus time (in minutes) to the first angiogram that showed patency of the infarct-related vessel (Angio Reperfusion Time). NR = five patients who did not have reperfusion demonstrated by electrocardiography within 180 min of initiation of therapy; p = successful rescue angioplasty; pp = primary angioplasty. Groups as defined in Figure 1.
Discussion

Although it is generally believed that ST segment monitoring may be a valid method to detect coronary reperfusion in acute myocardial infarction, various investigators (9–21) have reported inconsistent results. The present study provides explanations for these conflicting results and describes a method that provides optimal diagnostic accuracy. ST segment monitoring does not appear to correlate with late arterial patency. However, we report that early ST monitoring does appear to correlate very well with early patency. Furthermore, the evaluation of ST segment monitoring appears to be enhanced by quantitative computer-assisted measurement. Previous studies (9,10) that timed reperfusion in relation to visual qualitative “improvement” in ST segment levels may have led some to conclude that ECG diagnosis of reperfusion was not accurate. Angiographic assessment of coronary patency must be documented early during thrombolytic therapy, because late angiograms, performed hours after thrombolysis, will not reliably reflect the dynamics of coronary flow at the time of ST segment analysis (20–22,25–27). Among the recent studies of ST segment monitoring designed to correlate quantitative ST segment data with early coronary angiography (15–19,26), there were major differences in the ECG criteria of reperfusion and the reported accuracy of the test. Furthermore, the ECG recognition of reperfusion 2 to 3 h after initiation of therapy, as proposed in these studies, delays the performance of further interventions, which may limit their impact on infarct size. Our data demonstrate the feasibility of ECG recognition of coronary reperfusion within 60 min of initiation of therapy and, hence, validate the role of ST segment monitoring in the early management of acute myocardial infarction.

Resolution of symptoms. Previous studies (9,10,26) have concluded that the relief of ischemic symptoms after thrombolytic therapy is an unreliable predictor of coronary artery...
patency. The clinical value of resolution of chest pain as a marker of reperfusion is limited by its subjective assessment in patients often treated with sedatives and narcotic drugs. In addition, as cardiac myonecrosis progresses, symptoms will abate regardless of the patency of the infarct-related vessel. Our data concur with results of previous studies: The accurate recognition of coronary reperfusion at 60 min based on the presence or absence of chest pain had only modest significance for symptoms.

Baseline ST segment level. Previous investigators (9–21) have used the initial ST segment level as the baseline for ECG analysis. The recent recognition (26,28) of broad shifts in ST segment levels suggests that the magnitude of the initial ST level will vary depending on the timing of its measurement, and hence does not provide a stable fiducial point for ST segment analysis. The mechanism of the dynamic ST segment shifts during acute myocardial infarction has not been elucidated, but Hackett et al. (8) implied a correlation with a changing coronary vasomotor tone. Other postulates include the presence of injury currents that vary with time and amount of myonecrosis, and fluctuations in blood supply to the infarct zone. The present study reveals significant differences in the predictive power of ST segment monitoring depending on whether initial or peak ST segment levels are used as the baseline, largely as a result of these ST segment shifts. The rate of decline of ST segment levels among patients with coronary patency at 60 min was faster and a ≥50% reduction was reached a mean of 25 min earlier when values were measured from the peak rather than the initial ST level. The rapid reduction in peak ST segment levels in these patients explains the high sensitivity (96%) of the method tested in predicting coronary reperfusion within 60 min of initiation.
of therapy. The longer time required to reach a ≥50% decrement from initial ST segment levels led to considerable delays in the recognition of patency of the infarct-related artery at 60 min.

Resolution of ST segment elevation. Previous studies have used several different criteria for ECG evidence of reperfusion. Richardson et al. (27) defined a ≥2-mm decrease or normalization of ST segment levels as evidence for reperfusion and reported a sensitivity of 26% and specificity of 67%. Other investigators (16–20) have doubted the significance of absolute changes in ST segment levels and have examined instead fractional changes. Most reports (16,18,19,26) have suggested that a 50% decrease in ST segment levels is a simple and optimal criterion for diagnosing reperfusion, and have correlated lower fractional ST changes with poor specificity. Analysis of our data using the criterion of a ≥25% decrease in either initial or peak ST segment level yielded a specificity of only 44%, and the criterion of a ≥75% decrease led to a low sensitivity (41% to 54%). Krucoff et al. (15) considered the achievement of ST steady state within 100 min of thrombolytic therapy as a criterion for reperfusion and reported high predictive values. However, the detection of ST steady state in their study required continuous monitoring for ≥30 min after the resolution of ST elevation and may have resulted in unwarranted delays in the diagnosis of failed reperfusion. In the present study, ST segment monitoring was highly accurate in predicting the perfusion status of the infarct-related artery at 60 min, based on the presence or absence of a ≥50% decrement from peak ST segment levels within 60 min of initiation of therapy.

Timing of ECG analysis. Recent investigators (15–18) have delayed the ECG diagnosis of reperfusion to 2 to 3 h from the administration of thrombolytic therapy. In our opinion, an earlier diagnosis of failed reperfusion is essential for this test to have a clinical impact on the treatment of acute myocardial infarction. Hohnloser et al. (19) reported ECG data at 90 min but revealed disappointing results (60% sensitivity). The present study is the first to report accurate assessment of coronary artery patency (TIMI grade 2 or 3 flow) within 60 min of initiation of treatment in acute myocardial infarction. In patients with TIMI grade 3 flow at 60 min, the decline from peak ST segment elevation was faster, and the ECG criterion of reperfusion was met within 30 ± 15 min of initiation of therapy. The present study also demonstrates a lower sensitivity for detecting reperfusion in patients with later reperfusion (i.e., >60 min). In these patients, the slower decline of the ST segment could reflect either reperfusion with viability, and hence improvement of injury current, or persistent occlusion with completion of the myocardial infarction process. Others (16,27) have also found a decreased sensitivity and specificity when the period of ST monitoring for the detection of reperfusion was extended over hours. Hence, assessing reperfusion by ST segment monitoring >60 min after thrombolytic therapy may be less accurate and may result in unnecessary delays to further intervention.

Frequency of ST segment monitoring. Earlier studies (12–14,17,18) on ST segment monitoring in acute myocardial infarction compared static ECGs obtained at fixed time intervals. With the frequent shifts in ST segment levels, it became clear that frequent monitoring is essential to adequately record the dynamic nature of ST segment trends. Our data reinforce this concept and show significant reductions in the sensitivity of the test as the frequency of ST monitoring decreases. ST segment sampling intervals of ≥10 min led to an accurate correlation between coronary artery patency and the presence of a 50% decrement in peak ST segment levels at 60 min. In contrast, decreasing the frequency of ST segment monitoring to 15 to 20 min resulted in a lower sensitivity of the test and in missing of the actual peak ST segment level—and therefore in an attenuation in its observed height and full extent of its rate of decline—thus delaying the time to reach the 50% criterion and the diagnosis of reperfusion.

Limitations of the study. Some important limitations of our study merit emphasis. The patient group studied is relatively small. Nevertheless, significant differences were seen in the ST variables of reperfusion between those with and without angiographic reperfusion, and clear separation was also shown between those with TIMI grade 2 and grade 3 flow. Karagounis et al. (29) have suggested that TIMI grade 3 perfusion alone may best measure the reperfusion success of thrombolytic therapy, whereas TIMI grade 2 perfusion is generally insufficient to optimize myocardial salvage.

The primary drawback of ST segment tracking as a noninvasive marker of reperfusion is the need for computer-derived ST segment monitoring at the bedside. Our data were obtained from Holter recordings that were analyzed at a later time; nonetheless, the practical aspects of this method of monitoring coronary perfusion may be enhanced by the recent availability of real-time, computerized ST segment recorders (30,31) that allow ST monitoring at the bedside. Determining the time of ECG reperfusion on the basis of a ≥50% reduction in ST segment levels can be difficult because of wide fluctuations in ST segment levels around the 50% cutoff end point. We found that significant ST segment shifts before the time of reperfusion usually remained above the 50% level; seven patients did exhibit transient reductions in ST segment levels below the 50% level, but these lasted for ≥10 min. In our experience, the achievement of a 50% reduction in ST segment levels that lasted for >10 min correlated with a continuing decline in ST levels toward steady state. Previous investigators (12,13,18), citing potential limitations of the ECG in patients with low ST voltages, summated the ST segment levels in all affected leads. We have shown that the use of a selected single infarct-related lead is an adequate monitor of reperfusion. Although 42% of our patients had ≥3-mm initial ST segment elevation in a single lead, the ST levels subsequently increased in all and reperfusion was accurately predicted.

In the present study, no comparison was made between single-lead and 12-lead ST segment monitoring for the purpose of determining patency of the infarct-related artery. A recent publication (31) reported that continuous 12-lead monitoring...
in this setting was a useful marker of failed reperfusion. However, 12-lead monitoring is less practical for clinical use. Our method of single-lead monitoring is both simple and effective and resulted in impressive sensitivity and specificity.

Finally, the value of ST segment monitoring as a marker of reperfusion may be limited by the presence of bundle branch block, recurrent ventricular arrhythmia and old transmural infarction.

**Conclusions.** Our data suggest that ST segment monitoring of a single selected lead is useful in the management of acute myocardial infarction. The presence or absence of a $\geq 50\%$ decrease in peak ST segment levels within 60 min of the treatment of acute myocardial infarction shows promise as a noninvasive marker of the perfusion status of the infarct-related artery. To achieve optimal diagnostic accuracy, ST segment levels should be measured continuously or at least every 10 min.

We thank the Angiographic Core laboratory at Beth Israel Hospital, Boston, Massachusetts for reading the coronary angiograms. We appreciate the contributions of nurses and technicians in the cardiac catheterization laboratories, coronary care units and heart station of Jackson Memorial Hospital, Miami, Florida.

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**References**


