Prediction of 1-Year Mortality With Different Measures of ST-Segment Recovery in All-Comers After Primary Percutaneous Coronary Intervention for Acute Myocardial Infarction

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Background—Post hoc analyses from several randomized, controlled trials have established the prognostic importance of different measures of ST-segment recovery in highly selected patients undergoing primary percutaneous coronary intervention (PCI) for ST-segment–elevation myocardial infarction (STEMI). In this single-center registry, we investigated whether various measures of ST-segment recovery can be applied to unselected STEMI patients undergoing primary PCI.

Methods and Results—We analyzed 12-lead ECGs from 2124 consecutive STEMI patients who underwent primary PCI at our institution between November 1, 2000, and January 1, 2007. ECGs were recorded at the catheterization laboratory immediately before arterial puncture and at the end of PCI. We examined measures assessing ST-segment recovery on the postprocedural ECG and measures comparing both ECGs and related these to 1-year, all-cause mortality. Cumulative ST-segment recovery (∑ST-D resolution) at a 50% cutoff had the highest unadjusted accuracy (C statistic, 0.646; 95% confidence interval, 0.602 to 0.689; P<0.001) as compared with the other 8 measures evaluated. Furthermore, ∑ST-D resolution was the strongest contributor to both the net reclassification and integrated discrimination improvement.

Conclusions—Although each measure of ST-segment recovery provided univariable prognostic information, the ∑ST-D resolution measure comparing summed ST-segment deviations on the preprocedural and postprocedural ECG was the best independent predictor of 1-year mortality in all-comer STEMI patients after primary PCI. (Circ Cardiovasc Qual Outcomes. 2010;3:522-529.)

Key Words: ST-segment–elevation myocardial infarction ■ primary percutaneous coronary intervention ■ ST-segment recovery ■ prognosis

Despite successful epicardial recanalization, primary percutaneous coronary intervention (PCI) may be limited by suboptimal myocardial reperfusion caused by microcirculatory dysfunction, which is associated with adverse outcome.1,2 Noninvasive, simple, readily available methods to assess the success of mechanical reperfusion therapy at the tissue level after primary PCI will become increasingly important. ST-segment recovery on the 12-lead ECG can be measured in several different ways, reflecting successful microcirculatory reperfusion. Several post hoc analyses from randomized, controlled trials have established ST-segment recovery as a powerful predictor of prognosis in selected patients with ST-segment–elevation myocardial infarction (STEMI) undergoing primary PCI.3–11 Buller et al11,12 examined various, previously published measures of ST-segment recovery in the large cohort of 4866 STEMI patients who underwent primary PCI as part of the APEX-AMI trial. Conclusions from this ancillary study were generated with data from a highly selected population of patients with electrocardiographically large myocardial infarctions enrolled in a randomized trial. We investigated whether various measures of ST-segment recovery can be applied to an unselected primary PCI population with varying degrees of ST-segment elevation.

Methods

Source Population
The data analyzed in our study were obtained from STEMI patients who underwent primary PCI at the Academic Medical Center–University of Amsterdam between November 1, 2000, and January...
WHAT IS KNOWN

- Different measures of ST-segment recovery have shown its predictive value in patients with ST-segment elevation myocardial infarction included in randomized, controlled trials.
- The relative predictive value of different measures of ST-segment recovery in routine clinical practice is unclear.

WHAT THE STUDY ADDS

- Assessment of the predictive value of different measures of ST-segment recovery in an unselected, all-comer ST-segment–elevation myocardial infarction population undergoing primary PCI.
- This study found that a summed measure of ST-segment deviation on the preprocedure and postprocedure ECGs was the best predictor of 1-year mortality.

We obtained information on 1-year vital status from the institutional follow-up database of PCI patients. Patients are surveyed 1 year after PCI by means of a mailed, self-administered questionnaire. Follow-up information was synchronized with computerized, 1-year mortality records from the National Death Index and local authorities. We reviewed outpatients’ files and contacted general practitioners by telephone in case of conflicting or missing data.

Data Sources

From the local electronic database at the catheterization laboratory, we abstracted baseline demographic variables, procedural and angiographic information that had been prospectively collected and entered by specialized nurses and interventional cardiologists concurrently with routine patient care. This information included the operator’s online assessment of antegrade flow using the Thrombolysis In Myocardial Infarction (TIMI) scale, the extent of coronary artery disease, and the timing of reestablishment of antegrade flow through the infarct-related artery.

ECG Collection and Analysis

We retrospectively sought to collect 12-lead ECGs recorded immediately before arterial puncture for all STEMI patients who underwent primary PCI at our institution between November 1, 2000, and January 1, 2007, were eligible for inclusion. We excluded patients who underwent primary PCI of the left main coronary artery or a bypass graft. Patients whose preprocedural or postprocedural ECG could not be retrieved were excluded from this analysis. Furthermore, patients with a complete left bundle-branch block, an accelerated idioventricular rhythm, a paced rhythm, or severe ECG artifacts that prohibited accurate ST-segment evaluation were excluded. STEMI patients accepted for primary PCI whose ST-segment elevation had resolved on arrival at the catheterization laboratory were also excluded.

Statistical Analyses

The relation between all-cause mortality at 1 year and different ST-segment recovery measures was investigated with the use of Cox proportional hazards regression in 2 sets of models: crude models and models adjusted for baseline and procedural characteristics that showed a univariate association (P<.10) with 1-year mortality (sex, age, current smoking, the presence or absence of diabetes mellitus, hypercholesterolemia, a history of myocardial infarction or coronary artery bypass grafting, postprocedural TIMI flow, anterior STEMI, multivessel disease, use of GP IIb/IIIa inhibitors, and intraaortic balloon counterpulsation).

Various measures of ST-segment recovery were subdivided in 2 categories with a cutoff at 50% or in 3 categories with cutoffs at 30% and 70%, as previously described in literature.14–16 Worst-lead residual ST-E measure was subdivided into 3 categories: <1, 1 to <2, and ≥2 mm.4,17 Because previous validation of the worst-lead residual ST-E measure with abovementioned cutoff points was done at 30 to 240 minutes after the procedure,4,17 we investigated this measure of ST-segment recovery also with cutoff points at 2 and 4 mm residual ST-D was investigated at a 9-mm cutoff (median). Hazard ratios (HR) with 95% confidence intervals (CI) for death were computed with patients showing ≥70% ST-segment recovery, <1 mm residual ST-segment elevation, or ≤9 mm residual ST-D as a reference. ST-D resolution, single-lead ST-E resolution, worst-lead residual ST-E, and residual ST-D were also evaluated as continuous variables and HRs (95% CIs) were expressed for the per-unit (percentage or millimeters) increase of ST-segment recovery. These continuous variables were then concurrently forced into both crude and adjusted models to determine their independent strength to predict 1-year mortality.

To estimate the discriminative value of predictive models, we calculated the C statistic (area under the receiver operating characteristic curve) for models based on prespecified baseline and procedural characteristics (referred model), on ST-segment recovery measures alone, and for combined models. Differences in C statistic after the addition of the different measures of ST-segment recovery to the referent model were estimated as described by DeLong et al.18 The discriminative power of the different measures of ST-segment recovery was further quantified with the method described by Pencina et al.19 We analyzed differences in patient’s individual measures of ST-segment recovery were calculated from the electronic data set with per-lead measurements: (1) ST-D resolution (percentage change in cumulative ST-segment deviation between preprocedural and immediately postprocedural ECG); (2) ST-E resolution (percentage change in cumulative ST-segment elevation between preprocedural and immediately postprocedural ECG); (3) single-lead ST-E resolution (percentage change in maximum-lead ST-segment elevation between preprocedural and immediately postprocedural ECG); (4) worst-lead residual ST-E (absolute amount of ST-segment elevation in most affected lead on postprocedural ECG); and (5) residual ST-D (absolute amount of cumulative ST-segment deviation on the postprocedural ECG).

In the case of missing leads or artifacts, patients were included if at least 50% of the corresponding, infarct-related leads were suitable for ST-segment analysis. Leads V1 to V6, I, and aVL were considered directly infarct-related in anterior myocardial infarction and leads II, III, aVF, V5, and V6 in nonanterior myocardial infarction.

Study Population

Consecutive STEMI patients who underwent primary PCI at our institution between November 1, 2000, and January 1, 2007, were eligible for inclusion. We excluded patients who underwent primary PCI of the left main coronary artery or a bypass graft. Patients whose preprocedural or postprocedural ECG could not be retrieved were excluded from this analysis. Furthermore, patients with a complete left bundle-branch block, an accelerated idioventricular rhythm, a paced rhythm, or severe ECG artifacts that prohibited accurate ST-segment evaluation were excluded. STEMI patients accepted for primary PCI whose ST-segment elevation had resolved on arrival at the catheterization laboratory were also excluded.

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estimated probability of death with different predictive models. After addition of a ST-segment recovery measure to the referent model, each probability increase in a patient who died and probability decrease in a patient who survived would imply improved prediction ability, whereas the opposite implies worse prediction ability. We combined the numbers of improved and worsened probabilities for patients who died within 1 year and patients who survived in the net reclassification improvement. We also calculated the integrated discrimination improvement, which directly compares the mean difference in probability between models with and without the ST-segment recovery measures.

Normally distributed, continuous variables are expressed as means (±SD); other continuous data are expressed as median with interquartile range (IQR). All categorical variables are depicted using relative frequency distributions. Characteristics of patients who did and did not die within 1 year were compared using the χ² test to detect a trend for categorical variables; 1-way ANOVA or the Kruskal-Wallis test was used for continuous variables. For all tests, differences were considered significant if the 2-sided probability value was <0.05. Analyses were performed using SPSS software package (Version 15.0; SPSS, Inc, Chicago, Ill), Stata (Version 10; StatCorp LP, College Station, Tex), and R (R Foundation for Statistical Computing, Vienna, Austria).

Results

Study Cohort

A total of 3185 consecutive STEMI patients underwent primary PCI at our institution between November 1, 2000, and January 1, 2007. We excluded 67 patients who underwent primary PCI of the left main coronary artery or a bypass graft and 508 patients because of missing ECG recordings. There were 2610 patients with a complete set of ECGs. ECG exclusion criteria were present in 132 patients, and preprocedural ST-segment normalization occurred in 354 patients (Figure). Baseline and procedural characteristics of the remaining 2124 patients, stratified by outcome at 1 year, are depicted in Table 1.

![Flow chart of patient selection.](image-url)

Table 1. Baseline and Procedural Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>All Patients</th>
<th>1-Year Survivors</th>
<th>Patients Who Died</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>2124</td>
<td>1958</td>
<td>145</td>
<td></td>
</tr>
<tr>
<td>Age, y (SD)</td>
<td>61.0 (12.8)</td>
<td>60.4 (12.6)</td>
<td>69.3 (12.9)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Male sex, %</td>
<td>72.1</td>
<td>72.9</td>
<td>62.1</td>
<td>0.007</td>
</tr>
<tr>
<td>Current smoking, %</td>
<td>46.3</td>
<td>47.7</td>
<td>28.3</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Diabetes mellitus, %</td>
<td>11.1</td>
<td>10.5</td>
<td>18.6</td>
<td>0.006</td>
</tr>
<tr>
<td>BMI, kg/m² (SD)*</td>
<td>26.6 (4.0)</td>
<td>26.5 (4.0)</td>
<td>26.4 (4.7)</td>
<td>0.27</td>
</tr>
<tr>
<td>Hypertension, %</td>
<td>31.0</td>
<td>31.1</td>
<td>29.7</td>
<td>0.78</td>
</tr>
<tr>
<td>Hypercholesterolemia, %</td>
<td>21.9</td>
<td>22.5</td>
<td>13.8</td>
<td>0.02</td>
</tr>
<tr>
<td>Previous MI, %</td>
<td>11.2</td>
<td>10.9</td>
<td>11.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Previous CABG, %</td>
<td>0.7</td>
<td>0.6</td>
<td>2.1</td>
<td>0.08</td>
</tr>
<tr>
<td>Previous PCI, %</td>
<td>6.9</td>
<td>6.9</td>
<td>4.1</td>
<td>0.23</td>
</tr>
<tr>
<td>Anterior MI, %</td>
<td>45.7</td>
<td>45.0</td>
<td>54.5</td>
<td>0.03</td>
</tr>
<tr>
<td>Multivessel disease, %</td>
<td>30.6</td>
<td>29.2</td>
<td>47.6</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Pre-PCI TIMI 3 flow, %</td>
<td>11.1</td>
<td>11.3</td>
<td>9.0</td>
<td>0.49</td>
</tr>
<tr>
<td>Stent inserted, %</td>
<td>87.5</td>
<td>87.5</td>
<td>86.9</td>
<td>0.80</td>
</tr>
<tr>
<td>GP IIb/IIIa inhibitor used, %</td>
<td>30.5</td>
<td>30.4</td>
<td>31.7</td>
<td>0.78</td>
</tr>
<tr>
<td>Post-PCI TIMI 3 flow, %</td>
<td>89.4</td>
<td>90.4</td>
<td>75.2</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>IABP inserted, %</td>
<td>6.8</td>
<td>5.3</td>
<td>26.2</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Total ischemic time, min. (25th, 75th percentile)†</td>
<td>172 (130, 250)</td>
<td>174 (130, 250)</td>
<td>180 (142, 270)</td>
<td>0.18</td>
</tr>
<tr>
<td>Peak CK-MB, µg/L (25th, 75th percentiles)‡</td>
<td>248 (131, 435)</td>
<td>240 (124, 422)</td>
<td>350 (201, 545)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Values are expressed as percentages unless otherwise stated.

SD indicates standard deviation; BMI, body mass index; MI, myocardial infarction; CABG, coronary artery bypass graft; IABP, intraaortic balloon pump; and CK-MB, creatine kinase MB.

Data available in *1864 patients, †1897 patients, and ‡1272 patients.
Electrocardiography

The preprocedural standard 12-lead ECG was recorded at a median time of 161 minutes (IQR, 115 to 234) after symptom onset and 11 minutes (IQR, 5 to 18) before restoration of flow through the infarct-related artery. The postprocedural ECG was recorded at the end of PCI at a median time of 33 minutes (IQR, 24 to 47) after flow restoration.

On average, 97% of the leads on each 12-lead ECG could be analyzed. On the preprocedural ECG, the median ST-segment deviation and elevation were 19 mm (IQR, 11.5 to 28 mm) and 13 mm (IQR, 8 to 20.5 mm), respectively. Maximum single-lead ST-E before PCI was at median 4 mm (IQR, 2.5 to 6 mm). The median ST-D resolution was 50% (IQR, 21% to 70%), ST-E resolution was 52% (IQR, 23% to 75%), single-lead ST-E resolution was 56% (IQR, 29% to 80%), and worst-lead residual ST-E was 2 mm (IQR, 1 to 3.5 mm).

Prognostic Accuracy of Different ST-Segment Recovery Measures

One-year follow-up was complete in 2103 (99%) patients. A total of 145 (6.9%) patients died within 1 year. As shown in Table 2, all unadjusted hazard ratios for 1-year mortality showed statistical significance, except for the 1- to 2-mm residual ST-segment elevation category within the worst-lead ST-E measure. The associations depicted in Table 2 did not substantially change when the analysis was restricted to patients with postprocedural TIMI-3 flow (data not shown).

As presented in the center panel of Table 2, ST-D resolution with a 50% cutoff showed the highest unadjusted predictive accuracy (C statistic, 0.646; 95% CI, 0.602 to 0.689; \(P < 0.001\)), whereas worst-lead residual ST-E showed the lowest accuracy to predict 1-year mortality (C statistic, 0.609; 95% CI, 0.565 to 0.652; \(P < 0.001\)). Predictive accuracy of worst-lead residual ST-E was substantially higher

### Table 2. Result of Unadjusted and Adjusted 1-Year Mortality Analyses for Different ST-Segment Recovery Measures as Categorical Variables

<table>
<thead>
<tr>
<th>Measure</th>
<th>Outcome</th>
<th>Death, %</th>
<th>HR</th>
<th>95% CI</th>
<th>(P)</th>
<th>C Statistic</th>
<th>HR</th>
<th>95% CI</th>
<th>(P)</th>
<th>C Statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\Sigma ST-D) resolution</td>
<td>(\geq 70)%</td>
<td>543</td>
<td>2.6</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>2.1</td>
<td>1.2-3.8</td>
<td>0.015</td>
<td>0.795</td>
</tr>
<tr>
<td></td>
<td>30% to 70%</td>
<td>670</td>
<td>6.2</td>
<td>2.4</td>
<td>1.4-4.4</td>
<td>0.003</td>
<td>0.641</td>
<td>2.1</td>
<td>1.2-3.8</td>
<td>0.015</td>
</tr>
<tr>
<td></td>
<td>&lt;50%</td>
<td>1078</td>
<td>3.2</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>3.2</td>
<td>1.8-5.7</td>
<td>&lt;0.001</td>
<td>...</td>
</tr>
<tr>
<td></td>
<td>&lt;50%</td>
<td>1025</td>
<td>10.7</td>
<td>3.5</td>
<td>2.4-5.1</td>
<td>&lt;0.001</td>
<td>...</td>
<td>2.6</td>
<td>1.7-3.8</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>(\Sigma ST-E) resolution</td>
<td>(\geq 70)%</td>
<td>631</td>
<td>3.2</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td></td>
<td>30% to 70%</td>
<td>845</td>
<td>6.6</td>
<td>2.1</td>
<td>1.3-3.5</td>
<td>0.004</td>
<td>0.628</td>
<td>1.8</td>
<td>1.1-3.1</td>
<td>0.025</td>
</tr>
<tr>
<td></td>
<td>&lt;50%</td>
<td>627</td>
<td>11.0</td>
<td>3.6</td>
<td>2.2-6.0</td>
<td>&lt;0.001</td>
<td>2.8</td>
<td>1.7-4.7</td>
<td>&lt;0.001</td>
<td>...</td>
</tr>
<tr>
<td></td>
<td>&lt;50%</td>
<td>980</td>
<td>10.3</td>
<td>2.7</td>
<td>1.9-3.9</td>
<td>&lt;0.001</td>
<td>2.2</td>
<td>1.5-3.2</td>
<td>&lt;0.001</td>
<td>...</td>
</tr>
<tr>
<td>Single-lead ST-E resolution</td>
<td>(\geq 70)%</td>
<td>729</td>
<td>3.8</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td></td>
<td>30% to 70%</td>
<td>836</td>
<td>6.3</td>
<td>1.7</td>
<td>1.1-2.6</td>
<td>0.028</td>
<td>0.626</td>
<td>1.4</td>
<td>0.9-2.2</td>
<td>0.187</td>
</tr>
<tr>
<td></td>
<td>&lt;50%</td>
<td>538</td>
<td>11.9</td>
<td>3.2</td>
<td>2.1-5.1</td>
<td>&lt;0.001</td>
<td>2.2</td>
<td>1.4-3.5</td>
<td>0.001</td>
<td>...</td>
</tr>
<tr>
<td></td>
<td>&lt;50%</td>
<td>1289</td>
<td>4.3</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>0.625</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Worst-lead residual ST-E</td>
<td>(&lt; 1) mm</td>
<td>205</td>
<td>2.4</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>0.609</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td></td>
<td>1 to &lt;2 mm</td>
<td>683</td>
<td>4.1</td>
<td>1.7</td>
<td>0.7-4.4</td>
<td>0.28</td>
<td>1.3</td>
<td>0.5-3.5</td>
<td>0.555</td>
<td>...</td>
</tr>
<tr>
<td></td>
<td>(\geq 2) mm</td>
<td>1215</td>
<td>9.2</td>
<td>3.9</td>
<td>1.6-9.5</td>
<td>0.003</td>
<td>2.7</td>
<td>1.1-6.7</td>
<td>0.038</td>
<td>...</td>
</tr>
<tr>
<td></td>
<td>&lt;2 mm</td>
<td>888</td>
<td>3.7</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td></td>
<td>2-&lt;4 mm</td>
<td>772</td>
<td>7.5</td>
<td>2.1</td>
<td>1.3-3.1</td>
<td>0.001</td>
<td>0.633</td>
<td>1.8</td>
<td>1.2-2.8</td>
<td>0.008</td>
</tr>
<tr>
<td></td>
<td>(\geq 4) mm</td>
<td>443</td>
<td>12.2</td>
<td>3.4</td>
<td>2.2-5.3</td>
<td>&lt;0.001</td>
<td>2.7</td>
<td>1.7-4.4</td>
<td>&lt;0.001</td>
<td>...</td>
</tr>
<tr>
<td>Residual ST-D</td>
<td>(&lt; 9) mm</td>
<td>1085</td>
<td>3.9</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>0.622</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td></td>
<td>(\geq 9) mm</td>
<td>1018</td>
<td>10.1</td>
<td>2.7</td>
<td>1.9-3.9</td>
<td>&lt;0.001</td>
<td>2.0</td>
<td>1.4-2.9</td>
<td>&lt;0.001</td>
<td>...</td>
</tr>
</tbody>
</table>

*In each model, the following variables were entered en block: sex, age, current smoking, the presence or absence of diabetes mellitus, hypercholesterolemia, a history of myocardial infarction or coronary artery bypass grafting, postprocedural TIMI flow, anterior STEMI, multivessel disease, use of GP IIb/IIIa inhibitors, and intraaortic balloon counter pulsation (C statistic, 0.779).
with cutoff points at 2 and 4 mm (C statistic, 0.633; 95% CI, 0.586 to 0.679). For all measures of ST-segment recovery, we observed a modest but statistically significant improvement in C statistic when the ST-segment recovery measures were individually added to the referent model containing patient and procedural predictors of 1-year mortality (C statistic, 0.779 in referent model to 0.789 in new models; all \( P < 0.001 \)).

Measures of ST-segment recovery were entered separately as continuous variables in models 1 to 4 and as continuous variables en block in model 5. As depicted in the upper panel of Table 4, all categorical measures of ST-segment recovery and \( \sum \) residual ST-D showed the highest unadjusted accuracy (C statistic, 0.653 and 0.655, respectively) (Table 3, center panel). Each unit increase in \( \sum \)ST-D resolution and single-lead ST-E resolution was associated with a 1.7% and 1.5% relative risk reduction, respectively. With the worst-lead ST-E and \( \sum \) residual ST-D measure, the relative risk of death increased with approximately 15% and 4%, respectively, with each millimeter increase. All 4 continuous measures remained predictive after multivariable modeling. When these continuous measures were concurrently forced into one model, \( \sum \) ST-D resolution was the strongest measure to predict 1-year mortality (\( P = 0.056 \)) along with \( \sum \) residual ST-D (\( P = 0.064 \)), whereas both single-lead ST-E resolution (\( P = 0.19 \)) and worst-lead residual ST-E were no longer predictive (\( P = 0.52 \)) (Table 3, lower panel). These differences in predictive power of the continuous measures did not substantially change after multivariable adjustment, except for \( \sum \) residual ST-D.

As depicted in the upper panel of Table 4, all categorical ST-segment recovery measures significantly contributed to the net reclassification improvement (all \( P \leq 0.003 \)). All but the single-lead ST-E resolution and the \( \sum \) residual ST-D measure significantly contributed to the integrated discrimination improvement. Moreover, \( \sum \)ST-D resolution with a cutoff at 50% was the strongest contributor to both the net reclassification improvement (0.58; \( P < 0.001 \)) and the integrated discrimination improvement (0.0087; \( P = 0.003 \)). As depicted in the lower panel of Table 4, \( \sum \)ST-D resolution, single-lead ST-E resolution, and \( \sum \) residual ST-D as continuuous variables significantly contributed to the net reclassification improvement, whereas worst-lead residual ST-E did not (0.16; \( P = 0.057 \)). \( \sum \)ST-D resolution was the only measure that significantly contributed to the integrated discrimination improvement (0.0054; \( P = 0.03 \)). Thus, \( \sum \)ST-D resolution as a continuous variable was the only measure that significantly contributed to both the net reclassification improvement and the integrated discrimination improvement.

**Discussion**

Our study confirms the powerful predictive value of various measures of immediate ST-segment recovery for 1-year mortality in an all-comer STEMI population undergoing primary PCI. Among various measures, \( \sum \)ST-D resolution consistently yielded the best improvement in terms of C statistic, net reclassification improvement, and integrated discrimination improvement. This pattern was most prominent when \( \sum \)ST-D resolution was applied as a categorical variable at a 50% cutoff.

Several previous studies confirmed the prognostic value of ST-segment recovery in STEMI patients undergoing primary PCI. Although these studies were carried out in various settings and with different patient populations, all showed that ST-segment recovery is a useful prognostic instrument in addition to well-established patient and procedural predictors of outcome. In the largest study published until now, ST-segment recovery was strongly associated with 90-day death, congestive heart failure, and shock. Buller et al.\(^ {11} \) showed no distinct differences in prognostic value between several different measures of ST-segment recovery. In agreement with previous smaller studies,\(^ {4,20} \) they suggested that the worst-lead residual ST-E would be the measure of choice because of its easy bedside applicability. The discrepancy between these results and the results presented in this paper might be explained, in part, by 3 key differences.

First, ST-segment recovery in this study was assessed at the end of PCI, before the patient left the catheterization laboratory. In our daily practice, with STEMI patients transported to the catheterization laboratory by ambulance after field triage and subsequent transfer to local hospitals soon

### Table 3. Results of Unadjusted and Adjusted 1-Year Mortality Analyses for Different ST-Segment Recovery Measures as Continuous Variables

<table>
<thead>
<tr>
<th>Model No.</th>
<th>Measure</th>
<th>Unadjusted HR (95% CI)</th>
<th>P</th>
<th>C Statistic</th>
<th>Multivariable-Adjusted* HR (95% CI)</th>
<th>P</th>
<th>C Statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( \sum )ST-D resolution, %</td>
<td>0.983 (0.977–0.988)</td>
<td>&lt;0.001</td>
<td>0.653</td>
<td>0.988 (0.982–0.994)</td>
<td>&lt;0.001</td>
<td>0.794</td>
</tr>
<tr>
<td>2</td>
<td>Single-lead ST-E resolution, %</td>
<td>0.985 (0.980–0.991)</td>
<td>&lt;0.001</td>
<td>0.642</td>
<td>0.990 (0.984–0.995)</td>
<td>&lt;0.001</td>
<td>0.795</td>
</tr>
<tr>
<td>3</td>
<td>Worst-lead residual ST-E, mm</td>
<td>1.148 (1.089–1.210)</td>
<td>&lt;0.001</td>
<td>0.628</td>
<td>1.096 (1.030–1.167)</td>
<td>0.004</td>
<td>0.790</td>
</tr>
<tr>
<td>4</td>
<td>( \sum )Residual ST-D, mm</td>
<td>1.039 (1.026–1.052)</td>
<td>&lt;0.001</td>
<td>0.655</td>
<td>1.024 (1.010–1.038)</td>
<td>0.001</td>
<td>0.793</td>
</tr>
<tr>
<td>5</td>
<td>( \sum )ST-D resolution, %</td>
<td>0.991 (0.982–1.000)</td>
<td>0.056</td>
<td></td>
<td>0.993 (0.983–1.002)</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Single-lead ST-E resolution, %</td>
<td>0.994 (0.986–1.003)</td>
<td>0.19</td>
<td></td>
<td>0.996 (0.988–1.005)</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Worst-lead residual ST-E, mm</td>
<td>0.960 (0.848–1.087)</td>
<td>0.52</td>
<td></td>
<td>0.976 (0.836–1.138)</td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( \sum )Residual ST-D, mm</td>
<td>1.028 (0.998–1.058)</td>
<td>0.064</td>
<td></td>
<td>1.015 (0.98–1.051)</td>
<td>0.40</td>
<td></td>
</tr>
</tbody>
</table>

*In each model, the following variables were entered en block: sex, age, current smoking, the presence or absence of diabetes mellitus, hypercholesterolemia, a history of myocardial infarction or coronary artery bypass grafting, postprocedural TIMI flow, anterior STEMI, multivessel disease, use of GP IIb/IIIa inhibitors, and intraaortic balloon counterpulsation.
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IIb/IIIa inhibitors, and intraaortic balloon counterpulsation.

hypercholesterolemia, a history of myocardial infarction or coronary artery bypass grafting, postprocedural TIMI flow, anterior STEMI, multivessel disease, use of GP 

minutes,20 and within 4 hours17 after the PCI procedure. By 

this measure at 30 minutes,11 (on average) 106 minutes,4 180 

study performed less well as compared with analyses with 

predict 1-year mortality. Worst-lead residual ST-E in our 

We showed that 

may be essential for further medical strategies and prognosis.

after completion of the procedure, early assessment of risk 

be essential for further medical strategies and prognosis. 

We showed that \( \sum \)ST-D resolution was the best measure to 

predict 1-year mortality. Worst-lead residual ST-E in our 

study performed less well as compared with analyses with 

this measure at 30 minutes,11 (on average) 106 minutes,4 180 

minutes,20 and within 4 hours17 after the PCI procedure. By 

choosing different cutoff points, we showed that the predic-

tive power of this measure may remain applicable when 

ST-segment recovery is assessed at the end of primary PCI. 

These dissimilarities in prognostic power may display the 

importance of ECG timing when using worst-lead residual 

ST-E to predict outcome. With the increase in regional 

organization of primary PCI with so-called “hub-and-spoke” 

centers and “drive-through” PCI in which patients are trans-
ferred to the catheterization laboratory by ambulances and 

returned to non–PCI-capable hospitals in their own region, 

the 12-lead ECG recorded before and at the end of the PCI 

procedure will become an important prognostic indicator. In 

addition, such prognostic indicators may serve as an impor-

tant performance measure to assess the quality of a primary 

PCI program.

Second, comprehensive comparisons between known mea-

sures of ST-segment recovery have predominantly been 

performed with data from randomized, controlled trials. In 

the largest ancillary study, all 4866 included patients presen-
ted within 6 hours and had anterior myocardial infarction or 

extensive inferior myocardial infarction, defined as ≥2 mm 

of ST-segment elevation in 2 inferior leads and ST-segment 

depression in 2 contiguous precordial leads for a total 

ST-segment deviation of ≥8 mm.11 As a result, 60% of the 

included patients had anterior STEMI, which raises the 

important question whether conclusions from this ancillary 

study can be applied to an everyday STEMI population. In 

our study, we included consecutive, all-comer STEMI pa-

tients undergoing primary PCI with varying degrees of 

ST-segment elevation and investigated whether different 

measures of ST-segment recovery would predict outcome. 

Other large studies on the prognostic properties of ST-

segment recovery measures in all-comer STEMI populations 

are scarce. De Luca et al20 showed a significant association 

between different ST-segment recovery measures and 1-year 

mortality in an unselected cohort of 1286 primary PCI 

patients. However, paired ST-segment analysis was available 

in only 1072 patients, and postprocedural ECGs were 

recorded at 180 minutes after PCI. Furthermore, only 4 measures 

were tested, which makes a clear comparison with the current 

study difficult.

Third, previous studies mainly used the C statistic to 
determine the prognostic power of different ST-segment
recovery measures. The C statistic (or area under the receiver operating characteristic curve) has initially been developed to analyze a test’s accuracy to distinguish between persons with and without a disease of interest. Furthermore, improvement of the C statistic by adding a significant marker to a multivariable model is often modest and thereby has limited impact on the receiver operating characteristic curve. In accordance with the analyses by Buller et al, we found only modest, nonintuitive differences in C statistic between the different multivariable-adjusted measures of ST-segment recovery. With the recently published net reclassification improvement and integrated discrimination improvement, we were able to further quantify the improvement of risk prediction offered by the different ST-segment recovery measures. With these additional methods, we could show that $\Sigma$ST-D resolution, when assessed at the end of the PCI procedure, is the most powerful measure for 1-year risk prediction in patients undergoing primary PCI for STEMI. Worst-lead residual ST-E showed a slightly lower C statistic in our initial analyses but as a continuous variable did not significantly contribute to either net reclassification improvement or integrated discrimination improvement.

Another important result of our analysis is that $\Sigma$ST-D resolution with a cutoff at 50% gave best improvement of risk prediction when assessed at the end of PCI. Along with our study, several previous studies showed that $\Sigma$ST-D resolution has prognostic power when assessed at various static time points after primary PCI. Reports by Schröder et al consistently stated that 30% and 70% cutoffs would be preferable for a stepwise risk stratification. In our study, $\Sigma$ST-D resolution with cutoffs at 30% and 70% also had good predictive power but was surpassed by $\Sigma$ST-D resolution at a 50% cutoff. The discrepancy between previous studies and current study with regard to the optimal cutoff might again be explained by the timing of ST-segment recovery. With the recently published net reclassification improvement at a 50% cutoff, the data collected by the National Death Index and local authorities, we are unable to directly address whether reinfarction, ventricular arrhythmias, heart failure, or noncardiovascular causes were driving mortality in the present STEMI cohort.

In unselected STEMI patients undergoing primary PCI, $\Sigma$ST-D resolution, comparing summed preprocedural and postprocedural ST-segment deviation, is the best independent predictor of 1-year, all-cause mortality when assessed at the end of PCI. The prognostic power of this ST-segment recovery measure is most explicit when a 50% cutoff is used. Although worst-lead residual ST-E has obvious advantages over serial assessments and complex calculations in the clinical setting, this observational study provides robust information on prognostic properties in favor of immediate ST-segment recovery measures comparing preprocedural and postprocedural ECGs.

Disclosures

None.

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