

Non-invasive prediction of reperfusion and coronary artery patency by continuous ST segment monitoring in the GUSTO-I trial

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In the GUSTO-I ECG ischaemia monitoring substudy, 1067 patients underwent continuous ST segment monitoring, using vector-derived 12-lead (406 patients), 12-lead (373 patients) and 3-lead Holter (288 patients) ECG recording systems. Simultaneous angiograms at 90 or 180 min following thrombolytic therapy were performed as a part of the prospective study in 302 patients.

Infarct vessel patency was established as TIMI perfusion grades 2 or 3 and occlusion as TIMI perfusion grades 0 or 1. Coronary artery patency was predicted from ST trends up to the time of angiography. Predictive values at 90 and 180 min after the start of thrombolysis were 70% and 82% for patency and 58% and 64% for occlusion, respectively. In retrospect, accuracy appeared greatest (79–100%) in patients with extensive ST segment elevation ($\geq 400 \mu\text{V}$), if both speed of ST recovery and extent of ST segment

elevation were taken into account. Although the three recording systems differed considerably in signal processing, no significant difference in accuracy was demonstrated among these systems.

We conclude that continuous ECG monitoring may help select high risk patients without apparent reperfusion who may benefit from additional reperfusion therapy. As ST recovery may occur early after the start of thrombolytics and accuracy of the test is related to peak ST levels, the use of on-line ECG monitoring devices on emergency wards and cardiac care units is recommended.

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Introduction

Early reperfusion and sustained patency of the infarct-related coronary artery are important determinants of survival in patients with myocardial infarction^[1–3]. More aggressive therapy may be indicated if thrombolytic therapy fails to open the occluded vessel or if reocclusion of an initially reperfused coronary artery occurs^[4]. Thus,

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continuous monitoring of the degree of ischaemia as a marker of vessel (re)perfusion status may help to guide thrombolytic or adjunctive therapy. Non-invasive signs of reperfusion of the infarct-related vessel include resolution of chest pain, the occurrence of accelerated idioventricular rhythm, normalization of the ST segment, or sudden worsening of ST elevation followed by a rapid decline, and measurement of specific cardiac proteins in plasma^[5–9]. Continuous monitoring of the ST segment is a promising, readily available, non-invasive technique for assessment of reperfusion and patency^[10,12]. Although many attempts have been made to establish criteria that predict reperfusion from serial standard ECGs, only a limited number of studies have prospectively assessed the value of continuous ST segment monitoring for early patency assessment in comparison with angiography^[8,13–18]. Therefore, we investigated the ability of continuous ST segment monitoring to predict

reperfusion and patency in the context of the angiographic substudy in GUSTO-I (Global Utilization of Streptokinase and t-PA for Occluded coronary arteries)^[2,3]. The sensitivity, specificity and predictive value of predefined criteria for prediction of patency were tested in a large group of patients. A secondary objective was to investigate the similarities and differences among the three monitoring systems which were used in this study.

Methods

Study organization

The GUSTO-I ischaemia monitoring substudy mainly involved patients from the GUSTO-I angiographic substudy^[2,3] and, to a lesser extent, patients enrolled in the non-invasive part of the main GUSTO-I study. All patients underwent continuous ECG monitoring using either a vector-derived 12-lead ECG recording system, a 12-lead ECG recording system or a 3-lead Holter ECG recording system, as described below. Patients for this ECG ischaemia monitoring substudy were recruited by a total of 45 participating hospitals, situated in Europe, U.S.A., Canada, Australia and New Zealand. Each site was restricted to using only one type of recording device.

Patient selection

Patients were eligible for enrolment in the GUSTO-I study if they had chest pain lasting for at least 20 min, were within 6 h of onset of symptoms, and had electrocardiographic evidence of evolving myocardial infarction reflected by ≥ 0.1 mV ST segment elevation in two or more limb leads or ≥ 0.2 mV in two or more contiguous precordial leads^[2]. At the participating sites, all patients enrolled in the main GUSTO-I trial were considered eligible for the ECG ischaemia monitoring substudy except those with left bundle branch block, third-degree AV block, persistent arrhythmias or pacemakers.

Continuous ST segment monitoring

Eligible patients were monitored by either vector, 12-lead or 3-lead continuous Holter ECG, preferably within 30 min of the start of thrombolytic therapy. Continuous ECG recording was performed for at least 18 h from the start of thrombolytic therapy. The timing of the start of thrombolytic therapy and the moment of angiography were obtained from the study case record forms. An extensive report on the study design and technical considerations was published recently^[19].

Dynamic vector-derived 12-lead electrocardiographic recording system (MIDA 1000, Ortivus Medical, Täby, Sweden)

Twelve hospitals in Europe used the MIDA recording equipment. The MIDA system calculates averaged

QRS-T complexes from the Frank orthogonal leads X-Y-Z at 1-min intervals. All averaged complexes were stored on the hard disk and used for calculation of ST trend information. After completion of the recording, the averaged ECG data were stored on a floppy diskette and sent to the core laboratory at Cardialysis in Rotterdam, The Netherlands, for subsequent editing and analysis^[15,20]. Averaged 12-lead ECG complexes and 12-lead ECG trends were generated from the MIDA X-Y-Z leads, using the transformation formulae of Dower *et al.*^[21].

Continuously updated 12-lead ECG recording system (ST-100, Mortara Instrument, Milwaukee, U.S.A.)

The Mortara system, used in 15 hospitals in the U.S.A., calculates median beats of the 12-lead ECG every 15 s. These median beats are compared with the patient's baseline ECG in regard to ST segment changes over time in any lead. The system was programmed to store median beats if, in at least four consecutive median complexes, ≥ 200 μ V ST change was present in one lead, or if ≥ 100 μ V ST change was present in two contiguous leads. If little or no ST change was present, a median ECG complex was stored every 20 min. Subsequent editing and analysis were performed at the core laboratory of Duke University, Durham, U.S.A.^[11,13].

3-lead Holter ECG recording system (Marquette Electronics, Milwaukee, U.S.A.)

The Marquette Holter system, which continuously records three bipolar ECG leads, was used in 18 hospitals in Canada, U.S.A., Australia and New Zealand. Special lead configurations were applied to record inferior (left clavicle to left iliac crest), lateral (right clavicle to V₅ position), and anterior (spinous process between scapulae to V₂ position) ECG leads. The ECG recordings were archived on magnetic tape and sent to the core laboratory of St. Michael's Hospital in Toronto, Canada, for editing and analysis. ST trends of the three leads were generated by the Marquette review station, which averages ST levels from the recorded analogue ECG every 15 s^[22].

Differences among recording methods of the ECG

As described above, the methods and ECG handling properties of the three systems for generation of the ST trends were different: 1-min averaging for the vector-derived 12-lead system, 15-s medians for the 12-lead system (requiring a consistent change of ST amplitude during four consecutive median complexes, representing 1 min) or every 20 min and 15-s averaging for the 3-lead Holter system. This implies that the Holter system would be the most sensitive to abrupt ST changes and noise. To assess whether this would influence the ST trends, the other two algorithms were simulated using Holter trend data. One-minute averages (simulating the vector system) were obtained by averaging four consecutive Holter ST measurements (each originally representing 15 s of data). Similarly, the 12-lead (Mortara) algorithm was simulated by the requirement that a new

Table 1 ECG criteria for prediction of vessel status at angiography

| ECG criteria for prediction of vessel status | Expected vessel status at angiography |
|---|---------------------------------------|
| $\geq 50\%$ ST recovery from first peak ST level, no re-elevation $\geq 100 \mu\text{V}$ $\geq 50\%$ ST recovery from first peak ST level, followed by transient re-elevation $\geq 100 \mu\text{V}$, recovering before moment of angiography | 'patent' TIMI flow 2–3 |
| Absence of $\geq 50\%$ ST recovery before angiography | |
| $\geq 50\%$ ST recovery from first peak ST level, followed by re-elevation $\geq 100 \mu\text{V}$, persisting until moment of angiography | 'occluded' TIMI flow 0–1 |

measurement would be stored only after 20 min and whenever four consecutive measurements exceeded the boundaries as described above.

Editing and analysis of recorded data

ST trends of all recorded leads were produced at the three core laboratories. The ST segment level was measured at the J-point+60 ms. All ECG recordings and ST trends were manually scanned and edited for artifact, bundle branch block, detection or marker errors, positional changes and data gaps.

Visual patency assessment was performed until the moment of angiography. Patients whose recording began ≥ 1 h after initiation of thrombolytic therapy or who had an ECG recording gap of ≥ 1 h before angiography were excluded from the analysis. Patients with low-level ST amplitudes of less than $200 \mu\text{V}$ during the complete recording were also excluded.

The lead with maximal ST deviation at the onset of recording was selected for final ST analysis and visual patency assessment. If a 12-lead ECG prior to the start of the recording was available, this was used for selection of the lead with maximal ST deviation. For the Holter group, the most comparable lead of the three bipolar leads was chosen. As a consequence, the ST value of the first available ECG was considered to be the first ST value of the ST trend.

A visual analysis of the ST trend, validated by inspection of the actual ECG, was performed until the start of angiography. ST recovery criteria derived from previous studies were used for prediction of vessel status (Table 1)^[8,11,19,23,24]. If $\geq 50\%$ ST recovery from the first peak ST level was present immediately before angiography, the infarct-related vessel was predicted to be patent at angiography (Fig. 1(a)). In the absence of $\geq 50\%$ ST recovery before angiography, the vessel was predicted to be non-patent (Fig. 1(d)). Similarly, the

vessel was predicted to be non-patent if $\geq 50\%$ ST recovery was followed by re-elevation of $\geq 100 \mu\text{V}$ occurring within a 10-min time interval and lasting until the start of angiography (recurrent ischaemia, Fig. 1(c)). If before angiography, transient ST segment re-elevation fell below 50% of its own peak ST level or decreased to within $100 \mu\text{V}$ of the previous baseline ST level, the vessel was again predicted to be patent (Fig. 1(b)). All visual readings were done blinded to angiographic characteristics.

As it was expected that patency prediction would be influenced by peak ST levels and speed of ST recovery, retrospectively, four ST patterns related to pre-angiogram peak ST levels were studied for ability to predict vessel status at angiography: fast $\geq 50\%$ ST recovery within 45 min following thrombolysis or, compared to the previous study entry ECG, $\geq 50\%$ ST recovery already present at the start of the recording; $\geq 50\%$ ST recovery occurring within 45–90 min following thrombolysis; absent or late $\geq 50\%$ ST recovery (later than 90 min following thrombolysis); and persistently high or increasing ST levels. In the absence of ST re-elevation as described before, the first two patterns were regarded as predicting patency at angiography. The latter two were thought to predict a non-patent vessel.

Coronary angiography and angiographic analysis

In the GUSTO-I angiographic substudy, coronary angiography was performed according to stratified randomization at 90 min, 180 min, 24 h or one week after the start of thrombolytic therapy^[3]. Only patients with 90- and 180- angiography were selected for early electrocardiographic patency assessment. The coronary angiograms were sent to the core laboratory at the George Washington University, Washington, D.C. Angiographic assessments were made by experienced angiographers without knowledge of the electrocardiographic data^[3]. The angiograms were evaluated for flow in the infarct-related segment using the classifications of the Thrombolysis in Myocardial Infarction trial (TIMI) at first injection of contrast^[25]. TIMI perfusion grade 0–1 indicated an occluded coronary artery, TIMI perfusion grade 2–3 an open artery. Collateral flow was graded as none or minimal and moderate or large.

Data management

The edited and analysed data and final patency assessment scores were forwarded from the other core laboratories to the Ischemia Monitoring Laboratory at Duke University, Durham, N.C., U.S.A., for data entry, generation of queries for missing or inconsistent data, and final data-analysis. Subsequently, all data were returned to the other two core laboratories.

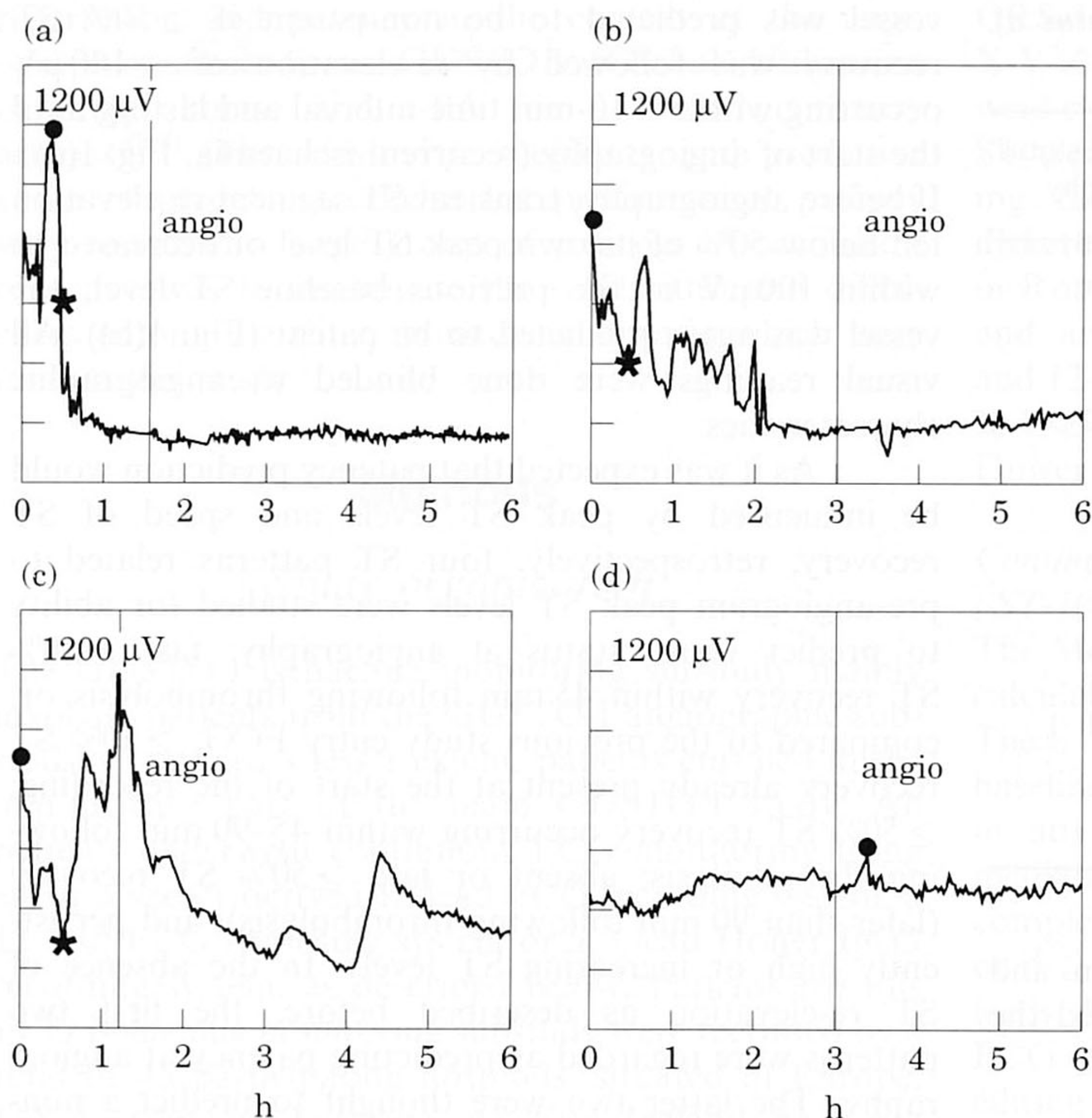


Figure 1 Assessment of patency from ST trend graphs. Visual analysis was performed until the moment of angiography (vertical line). ● = peak ST level; * = first moment of 50% ST recovery from peak ST level; (a) ST recovery within 45 min from start of thrombolytic therapy. No recurrent ST elevation. The vessel is predicted to be patent at the moment of angiography. (b) ST recovery within 45 min from start of thrombolytic therapy. Recurrent ST elevation episodes are present, but not at the moment of angiography. The vessel is predicted to be patent at the moment of angiography. (c) ST recovery followed by recurrent ST elevation, still present at the moment of angiography. The vessel is predicted to be non-patent at the moment of angiography. (d) Persistently high ST levels, no 50% ST recovery. The vessel is predicted to be non-patent at the moment of angiography.

Results

A total of 1067 patients were included in the ECG ischaemia monitoring substudy. Four hundred and six patients were monitored with the vector-derived 12-lead, 373 with the 12-lead system and 288 with the 3-lead Holter system. Four hundred and fourteen patients (39%) were excluded from analysis, mainly because of technical failures due to error on the part of the investigator (143 patients) because the recording started more than 60 min after initiation of thrombolytic therapy (139 patients). Sixty-three patients were excluded because in the hour prior to the start of angiography ECG and ST trend data were missing. Sixty-nine patients had low-level ST amplitudes less than 200 μV during the complete recording. Thus, 653 patients had ECG recordings suitable for further study and determination of the moment of first 50% ST recovery. Within the design of the GUSTO-I angiographic substudy, 302 of those patients also underwent angiography at 90 (224 patients)

or 180 min (78 patients) after initiation of thrombolytic therapy. This group of 302 patients was used for assessment of ECG prediction of vessel status. The infarct-related vessel was the left anterior descending artery in 137 patients, the right coronary artery in 121 and the left circumflex artery in 36.

Time to 50% ST recovery

Seventy-five percent of the 653 patients had 50% ST recovery within 90 min of initiation of thrombolytic therapy. Median times (25%, 75%) from initiation of thrombolytic therapy to 50% ST recovery were 50 (25, 107), 52 (25, 105) and 33 (15, 54) min for vector-derived 12-lead, 12-lead and 3-lead Holter, respectively (Fig. 2). The Holter system identified the moment of 50% ST recovery significantly earlier than either the vector-derived 12-lead or the 12-lead system ($P=0.0001$). The 12-lead entry ECG contributed to the determination of

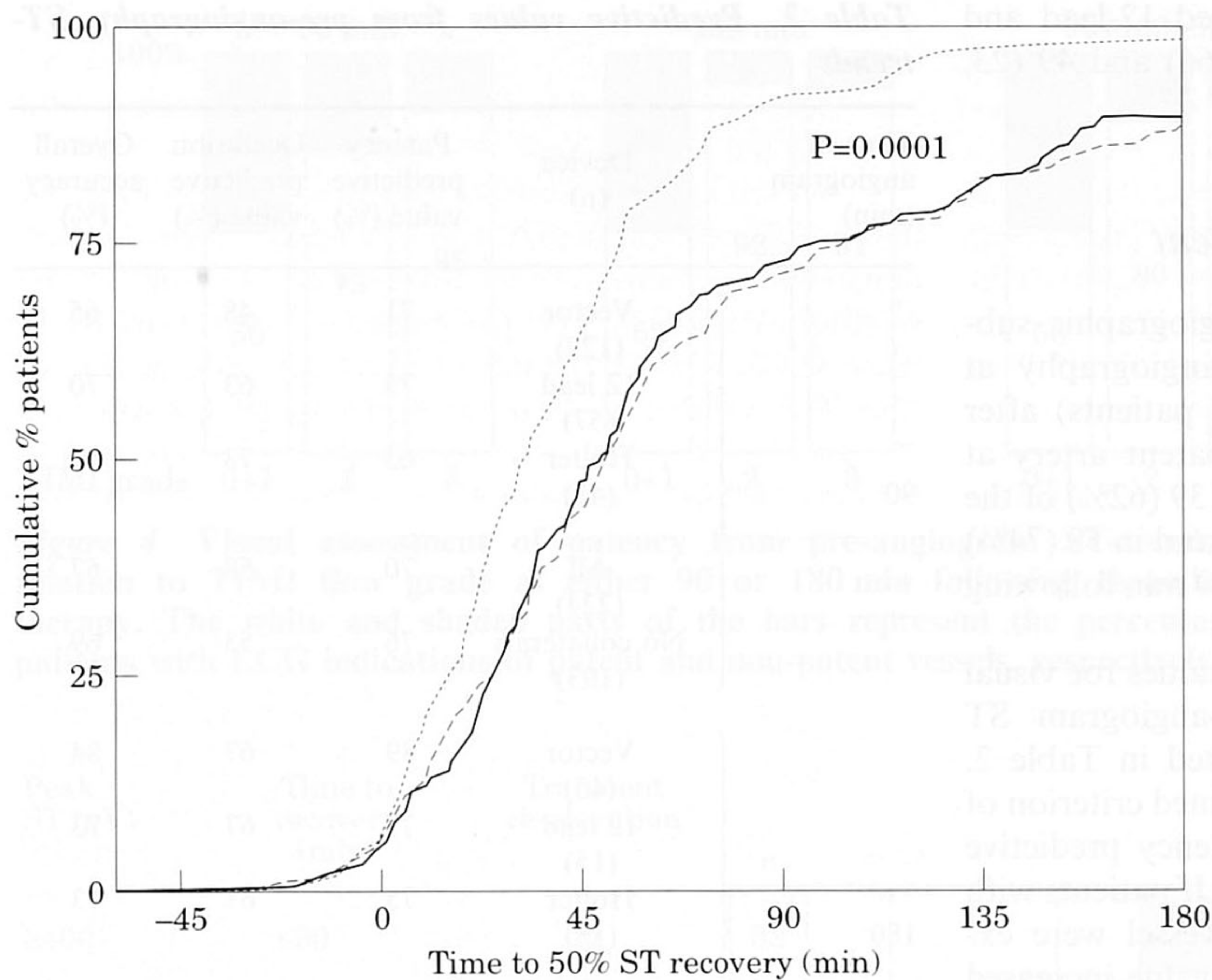


Figure 2 Cumulative percentage of patients exhibiting ST recovery plotted against the time from initiation of thrombolytic therapy to the first moment of 50% ST recovery for each ST monitoring system. \cdots =Holter (145 patients); — =vector (282 patients); --- =12 lead (226 patients).

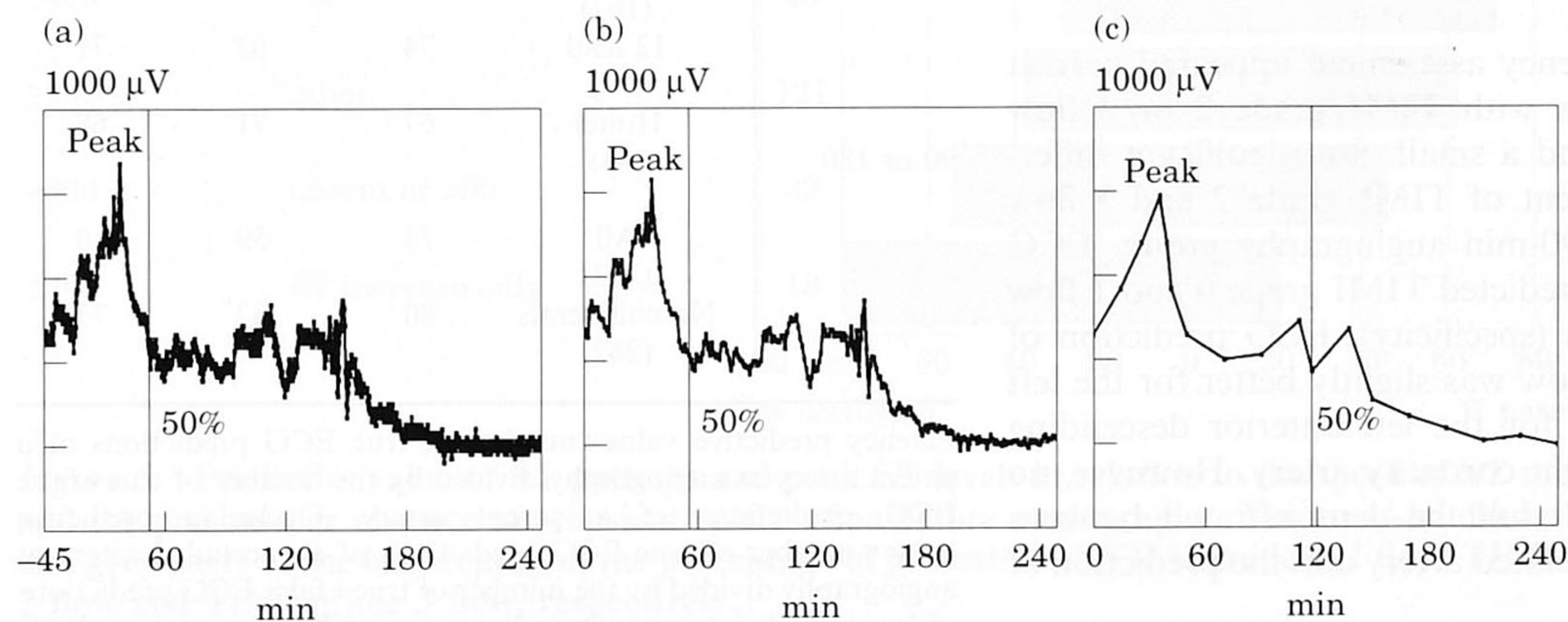


Figure 3 Effects of different algorithms on the moment of 50% ST recovery. (a) Example of a Holter ST trend recording using original 15-s averaged ST data. The first moment of 50% ST recovery occurs at 51 min from the start of the recording. (b) Simulated vector-derived 12-lead ECG ST trend of panel a, using 1-min averaged ST data. The first moment of 50% ST recovery occurs at 56 min from the start of the recording. (c) Simulated 12-lead ECG ST trend of (a), using either 15-s intervals, in the case of consistent 100 μV changes of ST amplitude, or 20-min intervals. The first moment of 50% ST recovery occurs at 110 min from the start of the recording.

the moment of 50% ST recovery in 37%, 35% and 53% for vector-derived 12-lead, 12-lead and 3-lead Holter, respectively. If these patients were excluded from the analysis, the differences in median time from initiation of thrombolytic therapy to 50% ST recovery persisted: 63 (35, 134), 58 (33, 126) and 47 (28, 71) min, respectively ($P=0.002$). To assess whether this effect could be attributed to the differences among the algorithms used by the three recording devices, the ECG sampling

algorithms of the vector-derived 12-lead and 12-lead ECG recording systems were simulated using the Holter ST trend data as the source data. Figure 3 illustrates a shift in detection of the moment of first 50% ST recovery that may occur when the original data of a Holter ST trend are transformed into a simulated vector-derived 12-lead and 12-lead ECG ST trend. Transformation of ST trend data from 145 Holter recordings confirmed that 50% ST recovery was present earliest in the Holter

and later in the simulated vector-derived 12-lead and 12-lead ST trends: 33 (15, 54), 37 (19, 66) and 49 (23, 90) min, respectively.

Visual patency assessment

Within the design of the GUSTO-I angiographic sub-study, 302 patients underwent early angiography at either 90 (224 patients) or 180 min (78 patients) after initiation of thrombolytic therapy. A patent artery at first injection of contrast was present in 139 (62%) of the 224 patients with angiography at 90 min and in 58 (74%) of the 78 patients with angiography at 180 min following thrombolytic therapy.

Overall accuracy and predictive values for visual assessment of patency from the pre-angiogram ST trends of these 302 patients are presented in Table 2. Patency predictive value using the predefined criterion of 50% recovery was 74% against non-patency predictive value of 59%. Overall accuracy was 70%. If patients with collateral filling of the infarct-related vessel were excluded (40 patients), patency predictive value increased to 80%, but non-patency predictive value decreased to 52% and overall accuracy remained almost unchanged. The 95% confidence limits of predictive values and accuracies of the three recording devices were wide, and no significant differences among the three systems were demonstrated.

The visual patency assessment appeared correct in 75–92% of patients with TIMI grade 2 or 3 flow (sensitivity, Fig. 4), and a small, non-significant difference between assessment of TIMI grade 2 and 3 flow was observed in the 90-min angiography group. ECG assessment correctly predicted TIMI grade 0 and 1 flow in 44–45% of patients (specificity). ECG prediction of TIMI grade 0 and 1 flow was slightly better for the left circumflex artery and for the left anterior descending artery than for the right coronary artery. However, no significant differences could be demonstrated between the site of the infarct-related artery and the prediction of vessel status.

Pre-angiography ST levels and ST patterns

The peak ST level, speed of ST recovery and $\geq 50\%$ ST recovery with transient re-elevation before angiography affected the accuracy of prediction of vessel status. A peak ST level of $\geq 400 \mu\text{V}$ was present in 116 patients (38%). Patency predictive value, non-patency predictive value and overall predictive accuracy of this group were 79%, 64% and 75% respectively, which were slightly better than those of patients with lower ST levels: 67%, 41% and 61% respectively (ns). As a retrospective observation, it appeared that if both $\geq 400 \mu\text{V}$ peak ST elevation and $\geq 50\%$ ST recovery with transient re-elevation within 90 min from start of thrombolytic therapy were present before angiography, the predictive value for TIMI grade 2–3 flow was 100% (33 patients,

Table 2 Predictive values from pre-angiography ST-trends

| Time of angiogram (min) | Device (n) | Patency predictive value (%) | Occlusion predictive value (%) | Overall accuracy (%) |
|-------------------------|----------------------|------------------------------|--------------------------------|----------------------|
| 90 | Vector (122) | 71 | 48 | 65 |
| | 12 lead (57) | 73 | 63 | 70 |
| | Holter (45) | 63 | 73 | 67 |
| | All (224) | 70 | 58 | 67 |
| | No collaterals (193) | 76 | 53 | 69 |
| 180 | Vector (45) | 89 | 67 | 84 |
| | 12 lead (15) | 75 | 67 | 73 |
| | Holter (18) | 75 | 67 | 73 |
| | All (78) | 82 | 64 | 79 |
| | No collaterals (69) | 89 | 50 | 84 |
| 90 or 180 | Vector (167) | 76 | 52 | 70 |
| | 12 lead (72) | 74 | 63 | 71 |
| | Holter (63) | 67 | 71 | 68 |
| | All (302) | 74 | 59 | 70 |
| | No collaterals (262) | 80 | 52 | 73 |

Patency predictive value=number of true ECG predictions of a patent artery at angiography divided by the number of true+false ECG predictions of a patent artery. Occlusion predictive value=number of true ECG predictions of an occluded artery at angiography divided by the number of true+false ECG predictions of an occluded artery. Overall accuracy=number of true ECG predictions of vessel status at angiography divided by the number of true+false ECG predictions of vessel status at angiography.

Fig. 5). Similarly, a predictive value of 79% was found for TIMI grade 0–1 flow if both $\geq 400 \mu\text{V}$ ST elevation and a pattern of persistently high or increasing ST levels were present (18 patients). Thus, by the combination of peak ST levels, speed of ST recovery and ST recovery with transient ST re-elevation before angiography, prediction of vessel status was 79–100% accurate in a subgroup corresponding to 29% of all angiographic patients studied.

Discussion

The present report is part of the GUSTO-I ECG ischaemia monitoring substudy and represents the largest

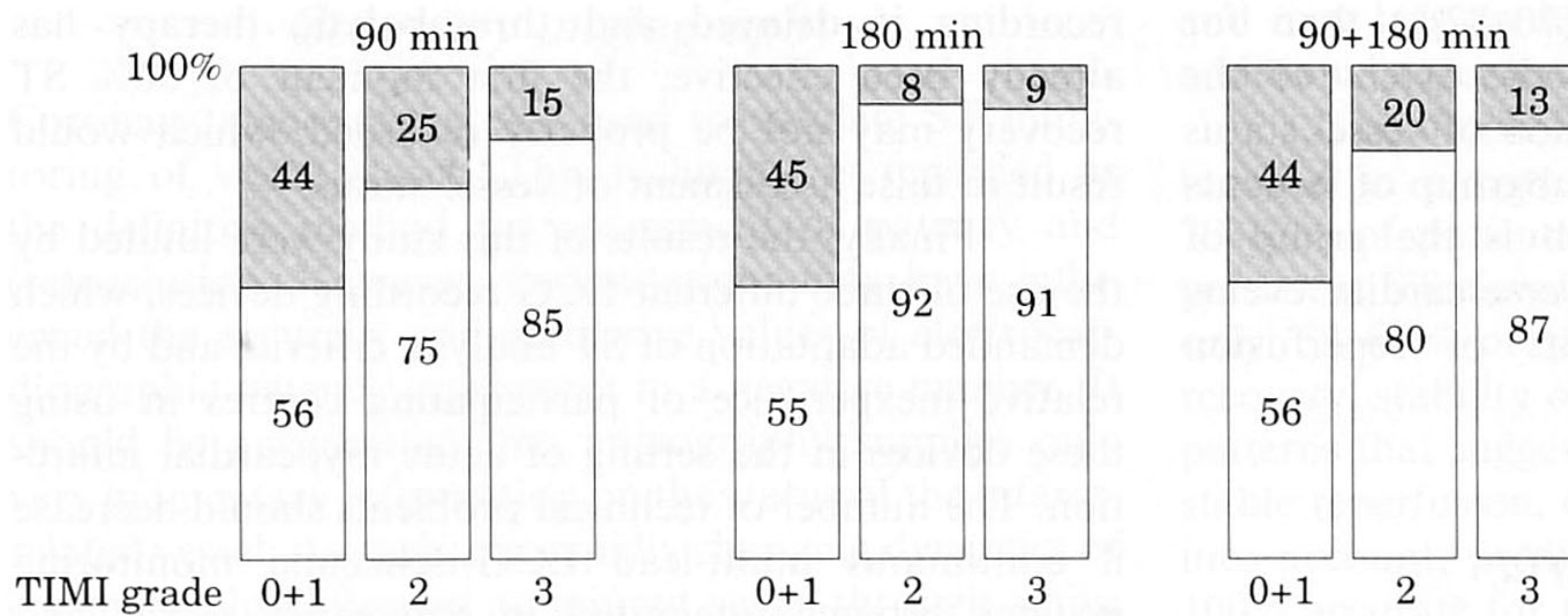


Figure 4 Visual assessment of patency from pre-angiogram ST-trends and relation to TIMI flow grade at either 90 or 180 min following thrombolytic therapy. The white and shaded parts of the bars represent the percentage of patients with ECG indications of patent and non-patent vessels, respectively.

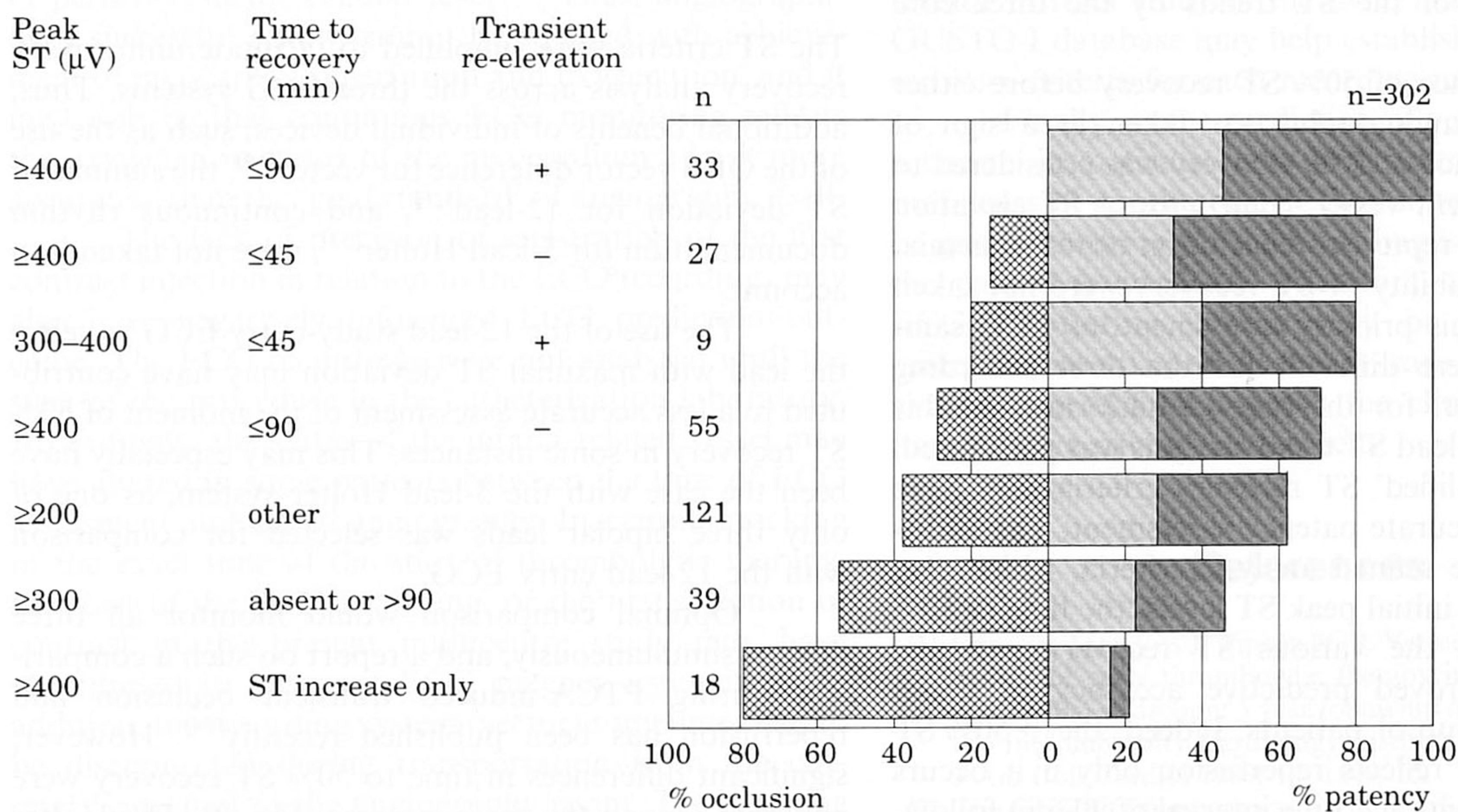


Figure 5 Predictive value of ST patterns and peak ST levels in relation to the speed of ST recovery and the presence or absence of transient re-elevation before angiography. The cross-hatched, dotted and grey parts of the bars represent the percentage of patients with TIMI grade 0-1 flow, TIMI grade 2 flow and TIMI grade 3 flow, respectively.

series comparing ST recovery analysis and early angiography during thrombolytic therapy. The purposes of the GUSTO-I ECG ischaemia monitoring substudy were (1) to compare the speed and stability of ST segment recovery across the four treatment arms of the GUSTO-I study, (2) to compare non-invasive patency assessment with simultaneous angiographic assessment and (3) to investigate whether different ECG recording techniques would give equal and comparable results. The present report focuses on the latter two objectives. The comparison among the four GUSTO-I treatment arms has been described recently in a separate report. In contrast to the results of the GUSTO-I main trial, this study did not demonstrate a difference in ST-recovery and recurrent ischaemia across treatment arms³⁸.

Many smaller studies have been conducted to determine the value of ECG monitoring for non-invasive prediction of vessel status after thrombolytic therapy for acute myocardial infarction^[7,8,11-18,23,24,26-31]. The total numbers of patients reported in the literature who were studied via early angiography plus serial ECG, Holter, or continuous ECG monitoring are 171, 118 and 261, respectively^[7,8,14-18,24,28]. The present study used simple, objective and unequivocally defined ST recovery criteria, derived from previous studies^[8,11,23,24]. The study design and the relatively large number of patients allowed us to study non-invasive patency assessment at both 90 min and 180 min following thrombolytic therapy. The study demonstrates that non-invasive patency prediction using continuous ECG recording techniques is possible and may be used in clinical practice. The technique appears

better for prediction of patency (70–82%) than for occlusion (58–64%), depending on the extent of the initial ST segment elevation. Prediction of vessel status appeared 79–100% accurate in the subgroup of patients with initially high ST levels, which is the group of patients with the highest risk of adverse cardiac events and receiving the greatest benefits of reperfusion therapy^[4,32].

ST analysis criteria

The criteria for ST segment recovery used in this study were a simplification of ST criteria published previously^[8,11,23,24]. This simplification was applied to facilitate the use of three ST monitoring systems with different ECG handling properties and to allow uniform analysis of the ST trends by the three core laboratories.

The presence of 50% ST recovery before either 90- or 180-min angiography was taken as a sign of reperfusion, absence of 50% recovery was considered to predict a non-patent vessel, recurrence of ST elevation was considered to represent reocclusion or re-ischaemia. The speed and stability of ST recovery were not taken into account in this primary assessment, as ECG sampling intervals were different for the three recording systems. Moreover, for the sake of uniformity of this study, only single-lead ST trend analysis was performed. Thus, these 'simplified' ST recovery criteria may have resulted in less accurate patency assessment. The additional use of more refined analysis criteria, which also took into account initial peak ST levels, the time to 50% ST recovery and the various ST recovery patterns, substantially improved predictive accuracy of vessel status in a subgroup of patients. Indeed, the $\geq 50\%$ ST recovery criterion reflects reperfusion only if it occurs early, preferably within a time interval of 90 min following the start of thrombolysis. Otherwise a non-patent infarct-related vessel should be suspected.

Time intervals and technical limitations

Assessment of patency is relevant mainly during the first hours following thrombolytic therapy. The longer the time from onset of chest pain to start of the recording, the less the ST segment deviation at the start of the recording. As our study demonstrated, the amount of ST elevation present during the recording is a major determinant of the accuracy of patency prediction: less ST deviation at the start of the recording and during subsequent recording may result in less accurate prediction of vessel status. The same is true for the delay from start of thrombolytic therapy to start of the recording. The time from initiation of thrombolytic therapy to first evidence of 50% ST recovery was less than 90 min in 75% of patients. Thus, in order to detect ST recovery, the recording should be started early, preferably before the start of thrombolytic therapy. If the start of the

recording is delayed and thrombolytic therapy has already been effective, the first moment of 50% ST recovery may not be properly recorded, which would result in false assessment of vessel status.

Finally, the results of this study were limited by the use of three different ECG recording devices, which demanded adaptation of ST analysis criteria, and by the relative inexperience of participating centres in using these devices in the setting of acute myocardial infarction. The number of technical problems should decrease if continuous multi-lead ECG-ischaemia monitoring systems become integrated in emergency wards and coronary care units.

Differences among recording methods of the ECG

The ST criteria were simplified to facilitate uniform ST recovery analysis across the three ECG systems. Thus, additional benefits of individual devices, such as the use of the QRS vector difference for vector^[14], the summated ST deviation for 12-lead^[16], and continuous rhythm documentation for 3-lead Holter^[33], were not taken into account.

The use of the 12-lead study-entry ECG to select the lead with maximal ST deviation may have contributed to a less accurate assessment of the moment of 50% ST recovery in some instances. This may especially have been the case with the 3-lead Holter system, as one of only three bipolar leads was selected for comparison with the 12-lead entry ECG.

Optimal comparison would monitor all three devices simultaneously, and a report on such a comparison during PTCA-induced transient occlusion and reperfusion has been published recently^[34]. However, significant differences in time to 50% ST recovery were apparent among the three systems (Fig. 2). The Holter system appeared to detect 50% ST recovery earliest. If ECG recordings were excluded in which the 50% ST recovery moment was determined by the entry ECG, this difference persisted, which confirms that the moment of 50% ST recovery is indeed dependent on the sampling algorithms used for generation of ST trends. Recalculation of Holter ST trend data into vector-derived 12-lead or 12-lead ST trend data confirmed that the earlier detection of 50% ST recovery was related to the short (Holter) averaging interval of 15 s. In fact, such shorter recording intervals will both facilitate early detection of rapid changes in the ST amplitude and be more sensitive to noise. Thus, adaptation of ST analysis criteria to the characteristics of each device may result in an improvement of predictive performance in these devices and in subsequent study results. It should be emphasized that in spite of the major differences in technologies, the reliability for prediction of vessel status appeared similar across the three recording devices. Nevertheless, the users of different systems must be aware of the technical features of these systems for correct interpretation of the signal^[35].

Coronary angiography

Coronary angiography was used to validate ST monitoring of vessel status. This technique is regarded as the definitive method for assessment of patency and (re)occlusion. However, its limitations may have influenced the accuracy and predictive values of electrocardiographic patency assessment in a negative manner. It should be appreciated that angiography supplies only very momentary information on the status of the infarct-related vessel. As such, the rapidly changing dynamics of coronary blood flow in an injured vessel through active thrombus formation, clot lysis, vasoconstriction and vasodilatation, cannot be assessed properly by this technique. Moreover, Ito *et al.* demonstrated that restoration of epicardial blood flow, as visualised by angiography, does not always correlate with restoration of perfusion at the cellular level^[36]. Thus, angiographically successful reflow cannot be equated with achievement of myocardial reperfusion and oxygenation, and it may well be that continuous ECG monitoring reflects the oxygenation status of the myocardium at risk more accurately than the 'gold standard' of angiography itself.

The lack of precision of registration of the first contrast injection in relation to the ECG recordings may also have negatively influenced ECG prediction outcome. The ECG recordings were not analysed until the start of the procedure in the catheterization laboratory. Accordingly, the status of the infarct-related vessel may have altered in some patients between the time of ECG assessment and actual angiography. Inaccurate tracking of the exact time of the start of thrombolytic therapy, the start of the ECG recording, or the first injection of contrast in the present multicentre study may have contributed to incorrect ECG patency assessment. In addition, the recording system (vector) sometimes had to be disconnected during transportation from the coronary care unit to the angiography room. The resulting ST trend data gaps between the moment of ECG assessment of patency and the start of angiography may also have resulted in less accurate prediction of vessel status, particularly for the vectorcardiographic system.

Conclusions

The present large study confirms the results of previous small studies, that continuous ST segment monitoring techniques may become clinically useful for prediction of reperfusion, patency and reocclusion during thrombolytic therapy.

Ellis *et al.* demonstrated that rescue PTCA after failed thrombolysis may improve clinical outcome, reflected by a reduction of combined heart failure and death ($P=0.055$) and an increase of left ventricular ejection fraction during exercise ($P=0.04$), within 30 days from the onset of myocardial infarction^[37]. This strongly points towards tailoring of reperfusion therapy^[4]. In this respect, continuous ECG monitoring techniques may assist the clinician in decision-making

and may help to select patients who may benefit from additional reperfusion therapy.

The simple ST recovery criteria used in this study resulted in a correct prediction of vessel patency in 70–82% of patients with ST recovery, but apparently persistent ST elevation predicted a non-patent vessel in only 58–64% of patients. However, if speed of ST recovery, stability of ST recovery and recognition of ST patterns that suggested either complete reperfusion, unstable reperfusion, occlusion or re-occlusion were taken into account, prediction of vessel status appeared 79–100% accurate for those patients having high initial ST levels. This subset of patients is at the highest risk of adverse cardiac events^[32] and will benefit most from additional 'rescue' procedures for failed reperfusion. Dynamic trend analysis and adaptation of ST analysis criteria to each recording method may yield even better results. Further study of the ECG and ST trends in the GUSTO-I database may help establish more refined ST recovery criteria for each recording method.

Finally, as the prediction of vessel status is most accurate in patients with high initial ST levels, the usefulness of continuous ECG monitoring systems may be greatly improved if the recording is begun as soon as the patient is admitted. Therefore, the use of on-line ECG monitoring devices may be recommended in emergency wards and coronary care units in order to avoid delay and to improve the clinical usefulness of non-invasive patency assessment

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