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ST segment analysis for assessment of coronary artery patency: comparison of surface ECG and Holter recordings

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In a prospective trial in 124 patients with acute myocardial infarction, Holter and surface ECG recordings were obtained simultaneously and compared for their ability to assess thrombolysis-induced ST segment changes. Accuracy in predicting patency of the infarct-related artery was evaluated in both methods. Success or failure of thrombolysis was determined angiographically 90 min after the start of therapy. For both methods, sensitivity, specificity, and positive predictive value for correct prediction of the perfusion status ranged between 64% and 92%. However, the negative predictive value was considerably lower (40–53%). There were no significant differences in any parameter evaluated for either method. Thus, two surface ECG recordings before and 2 h after the start of therapy yield the same predictive value as continuous Holter monitoring with respect to thrombolysis-induced coronary artery reperfusion. However, for triage of patients to early coronary interventions, more sophisticated methods are needed for non-invasive prediction of coronary artery patency due to the low negative predictive value of ST segment analysis.

Introduction

Thrombolysis has become the standard therapeutic approach in patients with acute myocardial infarction. The reduction of short- and long-term mortality as a result of thrombolytic therapy has been demonstrated in several large scale clinical trials[1–3], and coronary artery patency rates of 70–80% have been reported[4–6] with intravenous administration of newer thrombolytic agents. It has been demonstrated that impaired left ventricular function[7] and a persistently occluded infarct artery at discharge are associated with a poor prognosis[8,9], and patients with an occluded artery may thus benefit from early invasive procedures such as rescue coronary angioplasty[10,11].

To identify these patients, reliable non-invasive assessment of success or failure of thrombolytic therapy is mandatory, and the normalization of ST segment elevation can be utilized for this purpose[12–19]. Both Holter monitoring and serial surface ECG recordings have been used to assess reperfusion-associated changes of the ST segment.

Holter monitoring offers the advantage of continuous ST segment analysis during the presumed period of reperfusion, but evaluation of this recording is time-consuming and its results are highly dependent on the experience of the operator. In contrast, surface ECG recordings are simple to obtain but may be limited by the fact that they represent only a momentary picture of the rapidly changing ECG during the acute reperfusion phase. Only one study has used both methods simultaneously, but the number of patients involved was too low to compare the value of both methods[14]. In addition, ECG recordings were taken rather late after initiation of thrombolysis. The present investigation included 124 consecutive patients subjected to simultaneous recordings of Holter and serial surface ECGs in order to compare their utility for prediction of coronary artery patency following thrombolytic therapy.

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Methods

PATIENTS

One-hundred and twenty-four consecutive patients with acute myocardial infarction treated with thrombolysis were prospectively studied between May 1989 and November 1991. Patients with typical chest pain of ≥ 30 min duration, unresponsive to nitrates, and electrocardiographic ST segment elevation of $\geq 0{\cdot}1$ mV in at least two limb leads or $\geq 0{\cdot}2$ mV in at least two precordial (V) leads were eligible for the study. Thrombolytic therapy had to be initiated within 6 h of onset of symptoms. The thrombolytic agent used was pro-urokinase in 55 patients, combined with rt-PA in 20 patients, anisoylated plasminogen streptokinase activator complex (APSAC) in 43 patients, rt-PA in six patients, urokinase in four patients, and streptokinase in one patient. Following thrombolysis, all patients received a bolus of 7500 to 10 000 IU of heparin followed by a continuous infusion of 1250 IU . h^{-1} for the next 72 to 96 h (partial thromboplastin time adjusted to twice the upper normal). The usual exclusion criteria for thrombolysis were applied. The study was approved by the ethics committee of the University of Freiburg.

CORONARY ANGIOGRAPHY

Coronary angiography was performed 60 to 90 min after onset of thrombolytic therapy and repeated 24 h later. The angiographic findings were assessed according

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to the Thrombolysis in Myocardial Infarction (TIMI) criteria for reperfusion[5]. TIMI grades 2 and 3 were defined as coronary artery patency. For statistical analysis, early patency within the first 90 min was considered as successful coronary artery opening.

HOLTER MONITORING

Holter monitoring for analysis of the ST segment was initiated immediately before the start of thrombolytic therapy utilizing a commercially available Marquette Laser Holter system. Bipolar electrodes were placed in modified lead V_5 and aVF positions. The recordings were played back on a fully digitized AM-modulated[20] computer analysis system (Marquette Laser Holter). Continuous ST monitoring was carried out by measuring values at isoelectric, junction and ST setpoint (J+60ms) every 15 s. These standard set points of ST segment analysis were manually corrected after the start of the analysis when necessary. The resolution of ST segment elevation was further documented by print-outs (paper speed 25 mm . s^{-1}). ST segment elevation or depression were measured by two independent investigators who were blinded to the results of coronary angiography at the start of thrombolysis (0 min) and 120 min thereafter. From these measurements the maximal ST elevation of the two leads as well as the sum of ST elevations in both leads were determined.

SURFACE ELECTROCARDIOGRAM

Twelve lead surface ECGs were recorded before the start of thrombolysis and 120 min thereafter. ST elevation was measured at the J+s 60 ms-point for each lead by two independent investigators who were blinded to the coronary perfusion status. For each recording, the maximal ST elevation as well as the sum of all leads with ST elevation were determined.

STATISTICS

Values are given as mean ± standard deviation. Sensitivity, specificity, positive predictive value and negative predictive value were calculated according to the respective formulae. A Chi-square test was used to test the correlation of reduction of ST elevation to patency of the infarct artery. The Student's t-test for unpaired observations was used to compare ST elevations between two recordings: patients with and without coronary artery patency, and patients with anterior and inferior myocardial infarction. Receiver operator characteristic (ROC) curve analysis[21] was performed to compare the sums and the maximum ST segment elevation for both Holter and surface ECG with regard to their ability to predict, non-invasively, coronary artery patency. The difference between the areas between two ROC curves were compared by means of a univariate Z test[22]. Significance was considered with a P-value ≤ 0.05.

Results

CLINICAL DATA

One-hundred and nine patients were eligible for statistical analysis (88 males and 21 females at a mean age of 58 ± 11 years, range 32–84). Fifteen patients were excluded from the analysis due to the presence of left bundle branch block (n=3) or because of technical limitations of the Holter recordings. Fifty-three patients suffered from anterior and 56 from inferior infarction. The infarct-related artery was the right coronary artery in 47, the left anterior descending in 50, and the circumflex artery in 12 patients. Time from onset of chest pain to initiation of thrombolysis averaged 184 ± 100 min. In 82/109 patients (75%), TIMI grade 2 or 3 patency of the infarct artery was achieved within 90 min. In 27 patients (25%), the infarct artery remained occluded. Late reperfusion (between 90 min and 24 h) occurred in eight patients.

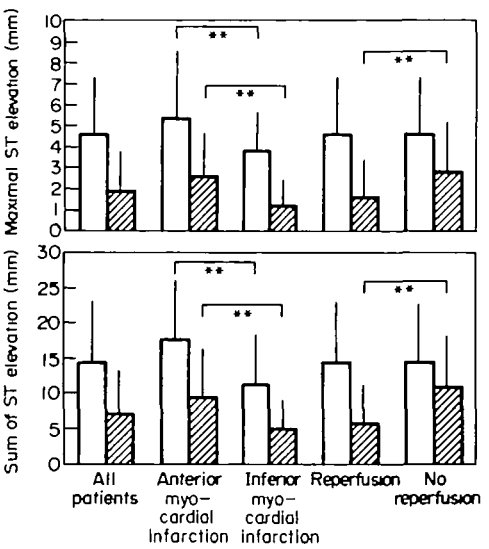

Figure 1 Upper panel. Maximal ST elevation ± SD in 12 surface ECG leads before and 126 ± 35 min after thrombolysis for all patients, patients with inferior and anterior myocardial infarction, and patients with and without patency of the infarct artery at 90 min. □ = ECG 1. ▨ = ECG 2. Lower panel: Sums of ST elevation in 12 surface ECG leads. Note differences in ST elevation according to infarct location and reperfusion status (** $P<0.01$). The differences between the first and the second ECG recording are significant for all patient groups at a $P<0.01$. □ = ECG 1; ▨ = ECG 2.

SURFACE ELECTROCARDIOGRAMS (FIG. 1)

The first ECG was recorded 41 ± 44 min before the start of thrombolytic therapy and the second 126 ± 35 min thereafter. The maximal ST elevation in the first recording was 4·6 ± 2·6 mm and the sum of ST elevations 14·4 ± 8·9 mm for all patients (Table 1). More than 1·5 mm maximal ST elevation was found in 95% of all patients, 94% of patients with anterior and 96% of patients with inferior myocardial infarction. In the second recording, a maximal ST elevation of 1·9 ± 1·9 mm and a sum of ST elevations of 7·1 ± 6·6 mm was found for all patients (Table 1).

For patients with coronary patency after 90 min, the maximal ST elevation was reduced by 65 ± 29% from 4·6 ± 2·6 mm in the first to 1·6 ± 1·7 mm in the second recording. Reduction of sums of ST elevation was

Table 1 Changes in maximal ST elevation and sum of ST elevations as determined from two surface ECGs

	ECG 1	ECG 2	% reduction
Maximal ST elevation			
Anterior infarction	5·4±2·9 mm	2·6±2·2 mm	51±32
Inferior infarction	3·8±2·0 mm	1·2±1·2 mm	64±35
Sum of ST elevation			
Anterior infarction	17·7±9·7 mm	9·4±7·6 mm	44±39
Inferior infarction	11·3±6·7 mm	4·9±4·7 mm	51±45

Table 2 Changes in maximal ST elevation and sum of ST elevations as determined from Holter monitoring before initiation of thrombolysis (Holter 1) and 120 min thereafter (Holter 2)

	Holter 1	Holter 2	% reduction
Maximal ST elevation			
Anterior infarction	2·7±2·4 mm	1·4±1·4 mm	33±43
Inferior infarction	2·9±2·0 mm	1·4±1·4 mm	41±54
Sum of ST elevation			
Anterior infarction	3·6±5·5 mm	2·0±2·26 mm	31±42
Inferior infarction	4·3±3·3 mm	2·2±2·0 mm	37±54

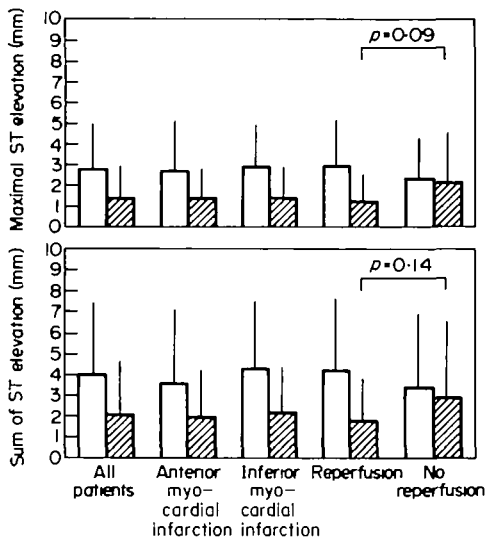

Figure 2 Upper panel: Maximal ST elevation ± SD in two Holter leads at the start of thrombolysis (0 min) and 120 min later for all patients, patients with inferior and anterior myocardial infarction and patients with and without patency of the infarct artery after 90 min. Lower panel: Sums of ST elevation in two Holter leads at the start of thrombolysis (0 min) and 120 min later ($P<0·01$). The differences between the first and the second recording are significant for all patient groups at a $P<0·01$ except for patients without reperfusion (P = ns). □ = Holter 0 min; ▨ = Holter 120 min.

56±40% from 14·4±9·1 mm in the first recording to 5·8±6·0 mm in the second, respectively. In patients with an angiographically occluded artery, reduction of maximal ST elevation was from 4·6±2·6 mm in the first recording to 2·8±2·1 mm in the second (−34±36%). The reduction of sums of ST elevation averaged 21±36% (14·4±8·4 mm in the first compared to 10·9±7·2 mm in the second ECG). Significant differences in ST elevation were noted between patients with anterior and those with inferior infarction, and between patients with and those without coronary artery patency (the latter only for the second ECG recording). Furthermore, the differences in ST elevation between the first and the second ECG recording were significant with a $P<0·01$ for all patient subgroups analysed.

HOLTER RECORDINGS (FIG. 2)

The maximal ST elevation before the start of thrombolysis (0 min) was 2·8±2·2 mm and the sum of ST elevations 4·0±3·4 mm (Table 2). More than 1 mm maximal ST elevation in two Holter leads was found in 79% of all patients, 74% of patients with anterior and 84% of patients with inferior infarction. At 120 min after the start of thrombolysis, a maximal ST elevation of 1·4±1·6 mm and a sum of ST elevations of 2·1±2·6 mm was found for all patients (Table 2). Patients with a patent infarct-related artery after 90 min exhibited a reduction of maximal ST segment elevation of 48±40% (from 2·9±2·2 mm at 0 min to 1·2±1·2 mm at 120 min), and of sums of ST elevation of 44±43% (4·2±3·4 mm at 0 min compared to 1·8±2·0 mm at 120 min). In patients with an angiographically occluded artery, reduction of maximal ST elevation averaged 3±57% (2·3±2·0 mm at 0 min compared to 2·1±2·5 mm at 120 min), reduction of sums of ST elevation 3±53% (3·4±3·5 mm at 0 min to 2·9±3·7 mm at 120 min).

COMPARISON OF PREDICTION OF CORONARY ARTERY PATENCY BY HOLTER AND SURFACE ECG VARIABLES (FIGS 3–5, TABLES 3 AND 4)

For comparison of the different variables for non-invasive prediction of coronary artery patency, sensitivity and specificity were calculated at various cut-off points (Figs 3 and 4) and by means of ROC curves (Fig. 5). The areas of ROC curves are listed in Table 1. Positive and negative predictive values were additionally calculated at three selected cut-off points (Table 4). Negative predictive values range between 40 and 53% for various cut-off points with both methods while sensitivity, specificity and negative predictive values were considerably better, ranging between 64% and 92%.

Discussion

In patients undergoing thombolysis for acute myocardial infarction, accurate non-invasive prediction of coronary artery patency is essential for triage of patients to further interventions[11]. Assessment of ST segment changes during the course of thrombolytic therapy can be used as a non-invasive marker[12–19]. The present study indicates that Holter and surface ECG recordings during the first 2 h of initiation of thrombolysis are equally suitable for this purpose. Analysis of two surface ECGs before and 2 h after initiation of thrombolysis appears to be the preferential method since the tracings

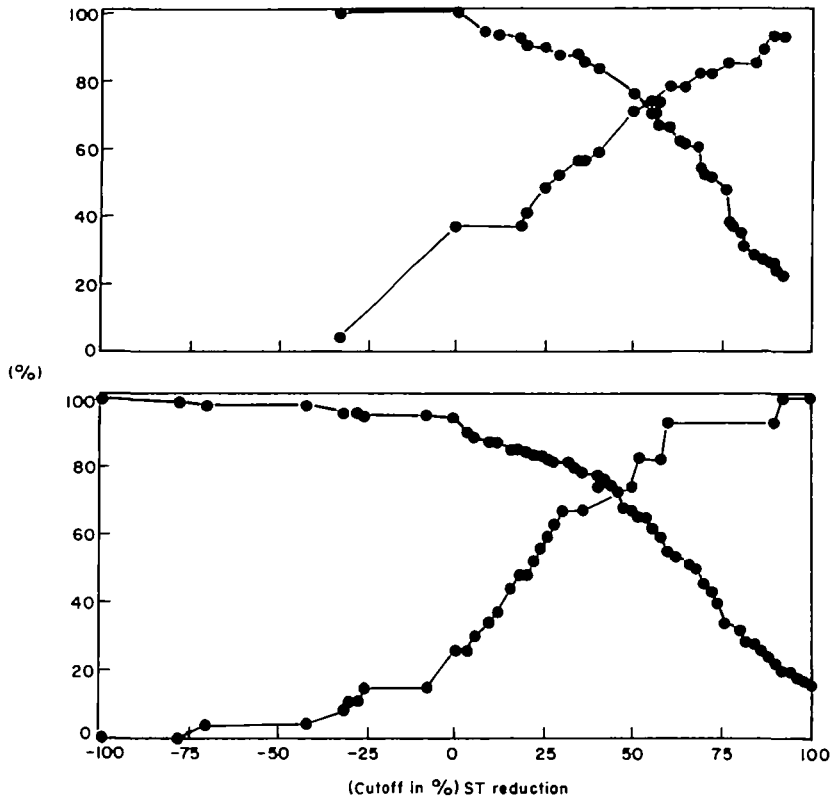

Figure 3 Sensitivity and specificity at various cut-off points for prediction of coronary artery patency 90 min after initiation of thrombolysis by reduction of maximal ST elevation (upper panel) and sums of ST elevation (lower panel) in 12 surface ECG leads before and 126 ± 35 min after thrombolysis.

can easily be obtained and immediately interpreted. Furthermore, Holter monitoring does not give on-line analysis for timely decisions about early coronary intervention.

The reduction of the maximal ST elevation in 12 surface or two Holter ECG leads and the decrease of sums of ST elevations within the first 2 h after thrombolytic therapy yielded comparable results concerning sensitivity, specificity, positive and negative predictive values for prediction of coronary patency. The optimal range of cut-off points for ST segment reduction was between 20 and 50%. These data agree with several studies investigating the value of ST monitoring for non-invasive prediction of success or failure of thrombolytic therapy. Hogg *et al.* studied the ST resolution after thrombolysis and found a reduction of ST elevation of 50% to be 100% specific and 93% sensitive for reperfusion of the infarct artery[14]. In a recent study from our institution applying the same criteria as Hogg *et al.*[14], ST segment reduction was found to be specific (94%) but less sensitive (60%)[16]. More recently, only a 25% reduction of the ST segment after 3 h was found to be more sensitive (97%) but not very specific (43%)[18]. Clemmensen and co-workers have confirmed that a rather small reduction of ST segment elevation appears to be the best cut-off for non-invasive detection of coronary artery patency[19]. They reported a 88% sensitivity and 80% specificity for a 20% decrease of the initial ST elevation after 60 min into thrombolysis.

Only one study compared surface and Holter ECG recordings with respect to their utility as non-invasive reperfusion markers[14]. However, this comparison is limited by the small number of patients involved in the study. Furthermore, the second surface ECG was recorded rather late after the start of thrombolysis (302 ± 141 min). In the present investigation of 109 consecutive patients, sensitivity, specificity and positive predictive value between 70 and 90% were determined for both methods. The good positive predictive value indicates that if a certain amount of ST reduction is noted within the first 2 h, coronary artery patency can be expected in up to 90% of patients. The negative predictive values for prediction of coronary artery patency, however, ranged only between 40 and 50% at various cut-off points. Thus, both surface ECG and Holter ST segment monitoring would result in false classification of a number of patients concerning their reperfusion status 90 min after thrombolysis. This particularly low negative predictive value may limit the utility of ST segment analysis for triage of patients with occluded infarct-related arteries to further interventions. For example, with a negative predictive value of 50%, only five out of 10 patients with predicted failed

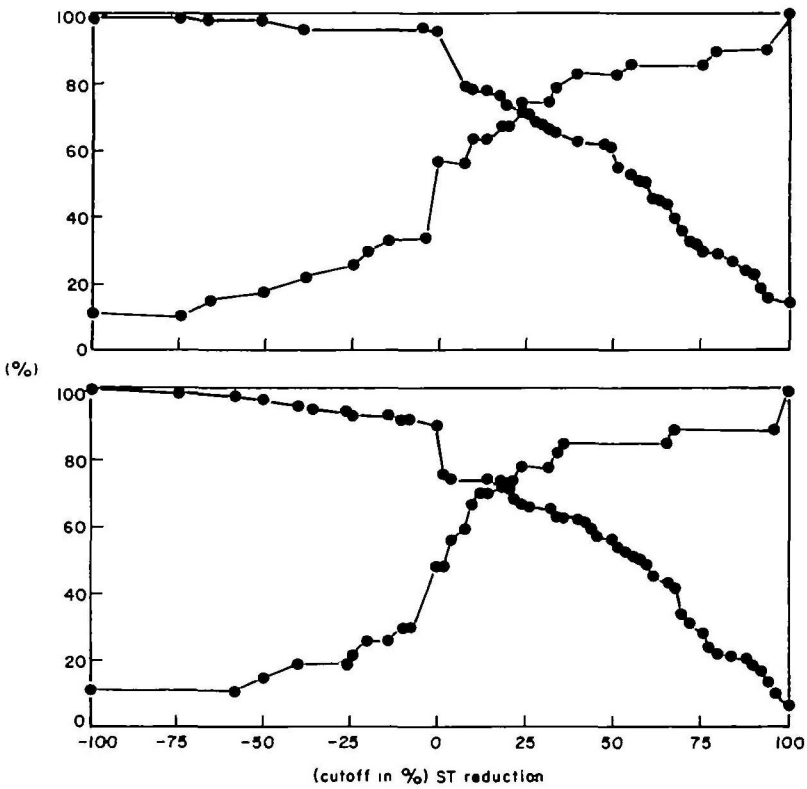

Figure 4 Sensitivity and specificity at various cut-off points for prediction of coronary artery patency 90 min after initiation of thrombolysis by reduction of maximal ST elevation (upper panel) and sums of ST elevation (lower panel) in two Holter leads with initiation of thrombolysis (0 min) and 120 min later. Note that the best cut-off point is at ST reductions below 25%.

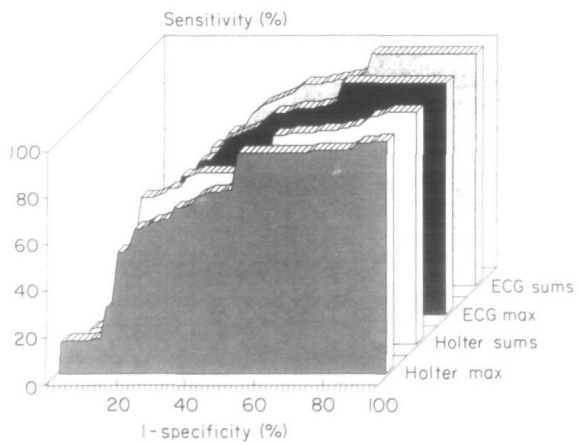

Figure 5 Receiver operator characteristics (ROC) curves for prediction of coronary patency 90 min after start of thrombolytic therapy by reduction of: sums of ST elevation in 12 surface ECG leads (ECG max), maximal ST elevation in 12 surface ECG leads (ECG sums), sums of ST elevation in two Holter leads (Holter max), maximal ST elevation in two Holter leads (Holter sums). There are no significant differences between the four parameters.

reperfusion, subjected to coronary angiography, would indeed be found to have an occluded infarct vessel. More accurate prediction of coronary artery patency can be achieved by the simultaneous use of several non-invasive reperfusion markers[23–28] as recently demonstrated in a study from our institution[16].

Not unexpectedly, the surface ECG analysis in this study revealed significantly higher ST elevations in patients with anterior compared to those with inferior myocardial infarctions. This difference, however, was not found by analysing the two Holter leads. Whereas the

Table 3 Receiver operator characteristics (ROC) curves for non-invasive prediction of a patent infarct artery by means of determination of reduction in maximal and sums of ST elevation in 12 surface ECG and two Holter leads. The P-value corresponds to the difference of ROC curve area from an area of 0·50 (indicating that a test is as predictive as chance)

Parameter	Area of ROC curve	*P*-value
Reduction of sums of ST elevation between ECG 1/2	0·77	<0·000
Reduction of maximal ST elevation between ECG 1/2	0·75	<0·000
Reduction of sums of ST elevation Holter 0–120 min	0·72	<0·000
Reduction of maximal ST elevation Holter 0–120 min	0·74	<0·000

Table 4 Sensitivity, specificity, positive (PPV) and negative predictive value (NPV) for non-invasive prediction of coronary artery patency by ST segment analysis in Holter and surface ECG at the best (printed in bolder characters) and two other cut-off points

Parameter	Cut off	Sensitivity	Specificity	PPV	NPV
Reduction of sums of ST elevation between ECG 1/2	30%	81%	67%	88%	53%
Reduction of sums of ST elevation between ECG 1/2	**40%**	**77%**	**74%**	**89%**	**50%**
Reduction of sums of ST elevation between ECG 1/2	50%	67%	74%	89%	43%
Reduction of maximal ST elevation between ECG 1/2	40%	83%	60%	85%	50%
Reduction of maximal ST elevation between ECG 1/2	**50%**	**76%**	**71%**	**85%**	**44%**
Reduction of maximal ST elevation between ECG 1/2	60%	66%	78%	89%	42%
Reduction of sums of ST elevation Holter 0–120 min	25%	67%	78%	90%	43%
Reduction of sums of ST elevation Holter 0–120 min	**35%**	**64%**	**85%**	**91%**	**42%**
Reduction of sums of ST elevation Holter 0–120 min	45%	59%	85%	92%	40%
Reduction of maximal ST elevation Holter 0–120 min	15%	77%	63%	86%	46%
Reduction of maximal ST elevation Holter 0–120 min	**25%**	**71%**	**74%**	**89%**	**44%**
Reduction of maximal ST elevation Holter 0–120 min	35%	65%	78%	89%	40%

used modified aVF Holter lead appears to have high sensitivity for ST elevation resulting from inferior infarction, the modified V_5 Holter lead may fail to detect the total amount of anteroseptal ST elevation, thereby explaining this difference. Furthermore, recording only two leads appears to be insufficient for Holter analysis in all patients. It is possible that vectocardiogram recording would enhance diagnostic accuracy[29]. Similar problems may relate to the finding that the difference between patients with and without coronary patency after 90 min was significant comparing the two surface ECG recordings, whereas the Holter analysis after 120 min revealed only borderline significance.

In addition to Holter analysis, on-line computer methods have been developed for continuous ST segment analysis. These have the advantage that data are immediately available and not off-line at a later stage, as with Holter[30,31].

CONCLUSIONS

Analysis of Holter and surface ECG recordings are equivalent methods to assess the resolution of ST segment elevation following thrombolytic therapy in acute myocardial infarction. Two surface ECG recordings before and 2 h after the start of thrombolysis offer a means of predicting patency of the infarct-related artery that is easy to perform. For triage of patients to early coronary interventions, simultaneous analysis of additional indicators of coronary artery patency, such as the occurrence of reperfusion arrhythmias or enzyme release as determined by rapid essays, appear to enhance the diagnostic accuracy[16].

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