Assessment of myocardial injury by serum tumour necrosis factor alpha measurements in acute myocardial infarction

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Clinical and experimental data have shown that after acute myocardial infarction there is a significant release of tumour necrosis factor alpha. Therefore, an attempt was made to correlate changes in serum tumour necrosis factor alpha concentrations with indices of infarct extent in patients with acute myocardial infarction.

In 50 patients with acute myocardial infarction, blood samples for evaluation of tumour necrosis factor alpha and alpha-hydroxybutyrate-dehydrogenase were collected every 6 h until 120 h after admission. Infarct extent was estimated by clinical parameters such as the occurrence of heart failure and rhythm disturbances, by enzymatic methods such as cumulative release of alpha-hydroxybutyrate-dehydrogenase and imaging techniques, by late resting single photon emission tomography — 201thallium scintigraphy — using an extent score and by echocardiography using a wall motion index. The maximum change in serum tumour necrosis factor alpha after infarction (∆TNF) was calculated by subtracting tumour necrosis factor alpha concentration on admission from peak tumour necrosis factor alpha concentration.

The average peak tumour necrosis factor alpha level was observed 84 h after admission (median: 12 pg. ml⁻¹). Between the 72nd and the 96th h no significant changes in tumour necrosis factor alpha values were observed. Analysis of the data showed that larger ∆TNF values were found to be associated significantly with signs of heart failure (P<0.003), the presence of rhythm disturbances (P<0.001), increased enzymatic infarct extent indicated by cumulative release of alpha-hydroxybutyrate-dehydrogenase (r=0.74; P<0.001), large myocardial perfusion defects measured with 201thallium scintigraphy (r=0.80; P<0.001), and a considerable number of left ventricular wall motion abnormalities (r=0.57; P<0.001).

In conclusion, ∆TNF is a reliable method of assessing damage severity in the myocardium after acute myocardial infarction. As only two blood samples are necessary within 84 h, the method may be one of the more convenient for the assessment of infarct size in clinical practice.

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Key Words: Myocardial infarction, tumour necrosis factor.

Introduction

Evaluation of the extent of acute myocardial infarction is important for predicting the subsequent clinical course and the prognosis of patients[4–9]. In previous studies, estimation of infarct extent has been based on serum enzyme elevation during the acute phase of infarction[4–6]. However, there was no strong correlation applicable for practical clinical use between changes in enzymes and myocardial infarction extent since the release of enzymes might be influenced by the degree of reperfusion and infarct localization[7–10]. Tumour necrosis factor alpha (TNF-α) is a hormone-like polypeptide with a variety of activities involved in the defence against pathogenic microorganisms and in the process of tissue repair[11]. In-vitro data revealed a significantly higher release of TNF-α from macrophages in patients with stable or unstable angina compared to patients without any evidence of coronary artery disease[12]. Additionally, an experimental porcine model demonstrated that after an ischaemic event, macrophages migrate into the ischaemic myocardium and release TNF-α locally[13]. The number of cells migrated into the myocardium increased until 72 h after vessel occlusion and remained constant over the next 3 weeks. There are also clinical data demonstrating a significant increase of TNF-α in patients with acute myocardial
infarction. In view of these experimental and clinical data, it can be assumed that after an ischaemic event macrophages that migrated into the myocardium are the source for the increased TNF-α in patients with acute myocardial infarction. The extent of infarcted myocardium is frequently assessed by the integration of clinical information, amount of non-contractile myocardium and also more recently by scintigraphic indices of severe and irreversible perfusion abnormalities in the ‘area-at-risk’. Thus, the goal of the present study was to investigate the correlation between parameters of infarct extent and changes in serum TNF-α concentrations in patients after acute myocardial infarction.

Methods

Patient selection

Between April 1993 and March 1994, 58 consecutive patients admitted to the emergency department with acute myocardial infarction were included in the study protocol. Acute myocardial infarction was diagnosed by a history of acute chest pain lasting for more than 30 min and persistent ST segment elevation as demonstrated on the ECG. Transmural infarction was confirmed by serial electrocardiographic abnormalities, with the development of Q waves lasting ≥0.04 s or longer as well as a typical rise and fall in levels of serum creatine kinase MB. Infarct location was defined as anterior if Q wave development occurred in leads I, aVL or V₂ to V₆ and as inferior if Q waves occurred in leads II, III or aVF. All patients received 100 mg rt-PA (Actilyse, Boehringer Ingelheim, GmbH, Ingelheim am Rhein, Germany) as thrombolytic therapy administered by accelerated frontloading. Treatment was preceded by an intravenous bolus of 5000 IU of conventional heparin, 5 mg intravenous propanolol and 100 mg aspirin orally. After thrombolytic therapy, conventional heparin and nitrates were given intravenously until normalization of creatine kinase MB (<10 U·1⁻¹). Eight patients were excluded for the following reasons: death within 24 h due to cardiogenic shock (n=2), absence of transmural infarction (n=4), prior myocardial infarction (n=2). The remaining 50 patients were 38 men and 12 women with a mean age of 55 ± 12 years (range: 34–75).

Definition of in-hospital complications after acute myocardial infarction

The complications studied were the presence of heart failure (class II, III, or IV according to Killip17) on the first day or persisting longer and the presence of major rhythm disturbances, which required therapeutic intervention (application of antiarrhythmic drugs, intravenous insertion of a temporary pacemaker, cardioversion or defibrillation).

Enzymatic infarct extent estimation

Blood samples for determination of α-HBDH were taken every 12 h until 120 h after acute myocardial infarction. Cumulative release of α-HBDH (HBDH₉₀₋₂) within the first 72 h was calculated by a two-compartment model described previously18.

Echocardiography

Two-dimensional echocardiography was performed on day 3 after acute myocardial infarction. A 16-segment model, as proposed by the American Society of Echocardiography, was used in the present study18. The severity of regional wall motion abnormalities was graded by a score for each segment: 1 = normal, 2 = hypokinesia, 3 = akinesia, 4 = dyskinesia. The wall motion index was calculated as the mean of visualized regional wall motion scores. Thus, a normal left ventricle would have a wall motion score index of 1. Theoretically, the maximal wall motion score index could be 4 if all segments were dyskinetic.

201Tl thallium scintigraphy

Thallium scintigraphy was performed between the 7th and 10th day after myocardial infarction. Following resting injection of 3–3.5 mCi of 201Tl-chloride, single photon emission tomography (SPECT) was performed with a rotating gamma camera. Early imaging was carried out 15 to 30 min after injection and 3–4 h later (late resting distribution). Only the late tracer distribution was taken into account for this study, as it had been shown to correlate with absence or presence of residual viability and thus the amount of severely underperfused and infarcted myocardium. Cross-sectional images in three standard slice orientations were obtained (16 slices for short axis, 8–12 slices for vertical long axis and 8–10 slices for horizontal long axis). From the late distribution of a short axis tracer, polar map analysis was carried out using count profiles which displayed information on all slices in a ‘target-like’ fashion19. From this polar map or ‘bull’s eye’ the extent score was calculated as the ratio of the defect area to the total area of the left ventricular myocardium in comparison to a validated normal database20.

Coronary angiography

Coronary angiography was performed between the 10th and 14th day after onset of myocardial infarction. The infarct-related artery was identified by assessing the electrocardiogram, the ventriculographic location of the contractile abnormality and the presence of stenosis or thrombus in the corresponding artery. Flow in the infarct-related artery was determined during the initial injection of the contrast agent and graded as described in the Thrombolysis in Myocardial Infarction (TIMI) trial21. According to TIMI grading, the patients were classified into two groups: patients without reperfusion of the infarct-related artery (TIMI grade 0 or 1) and patients with reperfusion of the infarct-related artery (TIMI grade 2 or 3).

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Blood sampling and handling

Blood samples were collected from patients through a venous cannula inserted in the forearm not used for administration of treatment, immediately before thrombolytic therapy and thereafter at intervals of 6 h up to 120 h to determine TNF-α. The first 5 ml were discarded and samples for TNF-α were collected into endotoxin-free evacuated glass tubes with sodium heparin (Chromogenix AB, Sweden). Samples were centrifuged within 10 min at 3000 g at 4 °C for 15 min. Plasma specimens of 500 μl were stored at −70 °C in plastic tubes. All patients gave their written informed consent for taking the additional blood samples.

Assay

The concentrations in plasma (pg . ml⁻¹) of TNF-α were determined with the use of an enzyme immunoassay according to the manufacturer’s instructions (Innotest h TNF-α; Innogenetics; Belgium). Purified TNF-α was used for construction of standard curves. The lower detection limit of TNF-α was 40 pg . ml⁻¹. The calculated overall intra-assay and interassay coefficient of variation was 6-5% and 7-6%, respectively.

Calculation and statistics

As TNF-α is detectable in about 50% of all healthy subjects,[22,23] we calculated the difference between the highest TNF-α concentration and TNF-α concentration on admission:

\[ \Delta (\text{TNF-α}) = \text{TNF-α}_{\text{max}} - \text{TNF-α}_{\text{admission}}. \]

Numerical data are given as mean (standard deviation, SD) or median (interquartile range, IQR) as appropriate. Differences in the TNF-α concentrations between the 72nd and 96th h after admission were calculated using the Wilcoxon signed rank test. Unpaired Student’s t-test was used to investigate differences between groups.[24-26] Simple and multiple regression was used to investigate associations between variables. All analyses were performed on the SPSS-release 6.0 statistical package (SPSS Inc., U.S.A.). P-values < 0.05 (two sided) were considered as statistically significant.

Results

Patients characteristics (Table 1)

Based on electrocardiographic data, myocardial infarction was located in the anterior wall in 24 patients and in the inferior wall in 26 patients. The location and patency of the infarct-related artery and the number of diseased vessels are summarized in Table 1.

<table>
<thead>
<tr>
<th>Reperfusion (TIMI 2.3)</th>
<th>No reperfusion (TIMI 0, 1)</th>
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<tbody>
<tr>
<td>TNF-α (pg . ml⁻¹)</td>
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<tr>
<td>12 h</td>
<td>48 h</td>
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<td>TIMI-0</td>
<td>TIMI-2</td>
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Table 1 Patient characteristics and results of coronary angiography performed between the 10th and 14th day after acute myocardial infarction. The infarct-related artery was identified by assessing the electrocardiogram, the ventriculographic location of the contractile abnormality and the presence of stenosis or thrombus in the corresponding artery. Flow in the infarct-related artery was determined during initial injection of contrast agent and graded as described in the Thrombolysis in Myocardial Infarction (TIMI) trial

Table 2 Median (interquartile range) TNF-α concentrations (pg . ml⁻¹) 12 h (TNF-α₁₂), 48 h (TNF-α₄₈) and 72 h (TNF-α₇₂) after acute myocardial infarction, according to the degree of reperfusion

Time course of TNF-α after acute myocardial infarction (Fig. 1)

The peak serum TNF-α concentration was 11.9 (10.1-16.3 pg . ml⁻¹) and was noted 84 h (range: 60 to 108 h) after admission. No substantial differences were observed between the 72nd and the 96th h after admission (Wilcoxon signed rank test: P = 0.25). Serum TNF-α was detected in 37 (74%) patients on admission. In contrast, in 13 (26%) patients serum TNF-α concentration was below the detection limit of 4.0 pg . ml⁻¹. Analysis of course of serum TNF-α with regard to the state of reperfusion is summarized in Table 2. After myocardial infarction, the course of serum TNF-α differed between patients with angiographically obtained reperfusion and patients without successful reperfusion. However, the differences did not reach statistical significance (12 h: P = 0.43; 48 h: P = 0.37; 72 h: P = 0.29: Table 2).
Changes in the median levels of TNF-α after admission in 50 patients with myocardial infarction. Between 72 and 96 h after admission no substantial changes in the TNF-α values were observed. Thus, it is sufficient to collect blood in the 24 h interval between 72 and 96 h in order to obtain meaningful information.

Median value; } = interquartile range.

To assess the relationship between infarct size and serum TNF-α concentration measurements, we examined the relationship between Δ(TNF) and infarct extent estimated by clinical parameters such as evidence of congestive heart failure or severe rhythm disturbances.

Congestive heart failure was observed in 18 (36%) out of 50 patients. In patients with evidence of congestive heart failure Δ(TNF) was significantly higher compared to those without any evidence of congestive heart failure (24.6 pg . ml⁻¹ (SD 7.3) vs 12.9 pg . ml⁻¹ (SD 14.3), P=0.003).

Rhythm disturbances were observed in 17 (34%) out of 50 patients. In patients with rhythm disturbances Δ(TNF) was significantly higher compared to those without rhythm disturbances (24.4 pg . ml⁻¹ (SD 13.6) vs 13.4 pg . ml⁻¹ (SD 8.7), P=0.001).

Infarct extent in-vivo was measured by enzymatic methods, such as cumulative release of α-HBDH, by imaging techniques, such as late resting SPECT-²⁰¹thallium scintigraphy using an extent score, and by echocardiography using a wall motion index.

Simple linear regression analysis revealed a significant association between the magnitude of Δ(TNF) and HBDH_{Q72}. The regression coefficient was 0.74 (P<0.001).

Simple linear regression analysis revealed a moderate but significant correlation between the magnitude of Δ(TNF) and echocardiographically obtained wall motion index (Fig. 3).
The influence of reperfusion and infarct location on the relationship between extent score and \( \Delta \text{(TNF)} \) was investigated by multivariate regression analysis. Extent scores did not correlate with the location of myocardial infarction \((r = -0.13, P = 0.16)\) or the degree of reperfusion \((r = -0.02, P = 0.74)\). In contrast, extent score was positively correlated with \( \Delta \text{(TNF)} \) \((r = 0.75, P < 0.001)\).

**Discussion**

The primary aim of the present study was to evaluate the relationship between changes in serum TNF-\( \alpha \) concentration and parameters of infarct extent in patients with acute myocardial infarction. The results demonstrate that the extent of changes in serum TNF-\( \alpha \) concentration are significantly related to estimates of infarct extent obtained scintigraphically. \( \Delta \text{(TNF)} \) also correlates well with other parameters such as the occurrence of heart failure, rhythm disturbances, enzymatic estimated infarct extent (HBDH \text{O}_{272}) and the wall motion index obtained echocardiographically.

A substantial increase of TNF-\( \alpha \) in patients with acute myocardial infarction was observed, which is in line with a previously published report demonstrating a similar course of TNF-\( \alpha \) in these patients\(^{14}\). Additionally, in-vitro data from a porcine model demonstrated that after an ischaemic event macrophages migrated into the myocardium and released TNF-\( \alpha \) locally. The number of cells immigrating into myocardium increased until the 3rd day after vessel occlusion and then remained constant over the next weeks. Accordingly, a proportional increase of TNF-\( \alpha \) concentration in the myocardium was observed\(^{13}\). Our data are in line with these experimental data as peak TNF-\( \alpha \) concentration was noted between the 60th and the 108th h after admission. We therefore assume that macrophages, which migrated into the myocardium after acute myocardial infarction, are the main source for the increased serum TNF-\( \alpha \) concentration in these patients. Our hypothesis is in line with experimental and postmortem data, which provide evidence for an accumulation of macrophages in ischaemic myocardium\(^{27,28}\). However, recent experimental data suggested that some of the TNF-\( \alpha \) released during myocardial ischaemia is produced by myocytes\(^{29,30}\). This is in contrast to clinical data illustrating that macrophages are the main source for the release of TNF-\( \alpha \) into the coronary sinus of the heart allograft\(^{31}\). Therefore, the exact cellular source of TNF-\( \alpha \) in patients with acute myocardial infarction remains controversial. Additionally, TNF-\( \alpha \) may also be produced by activated macrophages circulating in the peripheral blood. Experimental data about the production of TNF-\( \alpha \) from circulating macrophages in ischaemia/reperfusion models are lacking. However, Mazzone et al. demonstrated a transcardiac increase in the surface expression of CD11b/CD18 in coronary sinus monocytes and granulocytes when compared with simultaneous control samples drawn from aortic blood\(^{32}\). Therefore, it may be assumed that most TNF-\( \alpha \) is produced either by cells invading the myocardium or by resident cells. Our data, nevertheless, support the hypothesis that the release of TNF-\( \alpha \) into circulation is not confined to severe bacterial and parasitic infection, but occurs also as a result of non-infectious tissue injury\(^{33}\).

**Applicability of the method**

An essential limitation of enzymatic infarct extent estimation is the requirement of multiple blood samples collected at precise moments during the acute phase of myocardial infarction\(^{4,8}\). Van der Laarse et al. reported that HBDH-infarct extent could be calculated correctly only in 68% of all patients due to missing values\(^{8}\). As the TNF-\( \alpha \)-kinetic reveals no substantial changes in the TNF-\( \alpha \) values between the 72nd and the 96th h after admission, a period of 24 h seems suitable for blood sampling the maximum TNF-\( \alpha \) level. Therefore, the estimation of infarct extent using TNF-\( \alpha \) requires two blood samples only. We therefore assume that our method is convenient and easily applicable to daily clinical routine.
Influence of reperfusion

Previously published reports using enzymatic infarct extent estimation demonstrated the important influence of the degree of reperfusion on the kinetic of enzymes (e.g. CK, CK-MB, LDH and LDH-isoenzymes) since changes in myocardial blood flow contributed to the extent of released enzymes from infarcted myocardium\(^{9,10,34-36}\). In studies on dogs, however, the amount of CK in serum was twice as high per gram of infarcted myocardium after reperfusion, as compared with values in permanent occlusion\(^{101}\). Only about 15% of the CK activity depleted from the myocardium appears in the circulation, owing to inactivation during transport in the lymph. The increased rate of enzyme transit into the systemic circulation during a ‘wash-out’ could have reduced the extent of enzyme inactivation\(^{37}\). The ratio of the amount of CK depleted from myocardium to the amount that appears in serum differs for reperfused and non-reperfused animals\(^{109}\). Thus, the use of serial CK values for calculating infarct sizes is limited. Calculation of infarct size in reperfused patients is also complicated by the possibility that patients might have less than total coronary occlusion and that clot formation and spontaneous or drug-induced lysis may be a dynamic process. Analysis of the course of TNF-\(\alpha\) according to the grade of reperfusion revealed a difference in TNF-\(\alpha\) concentrations 12 and 48 h after myocardial infarction between patients with TIMI grade 2 or 3 and those with TIMI grade 0 or 1. Our data therefore support experimental findings which demonstrated a significantly higher number of macrophages in reperfused myocardium compared to non-reperfused myocardium\(^{28}\). However, the difference between the groups did not reach statistical significance. We therefore assume that the degree of reperfusion (expressed as TIMI grades) in the infarct-related artery might alter the course of TNF-\(\alpha\) concentrations within the first 48 h, but not influence the final relationship between serum TNF-\(\alpha\) and infarct extent obtained scintigraphically.

Influence of infarct location

The relationship between enzymatic estimation by previous approaches and infarct extent has been moderate to weak in patients with inferior wall infarction\(^{6,38}\). De Boer presented data about the correlation of cumulative LDH and infarct size in patients undergoing either intravenous thrombolytic therapy or percutaneous transluminal angioplasty. There was no correlation between left ventricular function and cumulative LDH in patients with inferior wall infarction undergoing thrombolytic therapy\(^{49}\). Our data reveal no influence of infarct location on the relationship between \(A(TNF)\) and infarct size. This would offer a potential assessment advantage in the clinical setting.

Pathophysiological significance of TNF-\(\alpha\)

Previous experimental and clinical studies have suggested that there is an association between depressed myocardial function and elevated levels of TNF-\(\alpha\)\(^{39,40}\). Our data support these findings, as the evidence of congestive heart failure was associated with higher TNF-\(\alpha\) values compared to patients without heart failure. As indicated by Yokoyama et al., TNF-\(\alpha\) induced abnormalities in the contractile function of myocytes due to an increase in intracellular calcium\(^{29}\). From this we assume that TNF-\(\alpha\) is partially responsible for the development of congestive heart failure in patients with acute myocardial infarction. In experimental studies it has been demonstrated that TNF-\(\alpha\) is an important stimulus for the expression of ICAM-1 on myocytes\(^{41}\). ICAM-1 is an adhesion molecule, which initiates the adherence of neutrophils on myocytes after reperfusion. This mechanism seems mainly responsible for the initiation of a reperfusion injury after successful reopening of an occluded coronary artery. We therefore assume that TNF-\(\alpha\) may play an important role in the inflammatory cascade after establishment of reperfusion as well as in the development of reduced myocardial contractility.

Limitations of the study

Several limitations of the study concerning the analysis of TNF-\(\alpha\) and in-vivo infarct size assessment have to be emphasized. As TNF-\(\alpha\) is also present in peripheral blood cells, inappropriate handling of the blood samples may result in wide variations of TNF-\(\alpha\) measurements. Therefore, TNF-\(\alpha\) measurement requires some laboratory experience and extremely careful handling of the samples such as early and thorough centrifugation. In vivo infarct extent estimation has certain obvious limitations, as the optimal standard for infarct extent determination would be postmortem examination\(^{43}\). The early assessment of wall motion indices by echocardiography is certainly limited, as the wall motion index contains a significant number of ‘stunned’ myocardium and thus would overestimate true infarct extent. However, radionuclide imaging by \(^{201}\)Thallium-scintigraphy, or more recently by \(^{99}\)Tc-Sestamibi scintigraphy, delineates the area-of-risk in patients after acute myocardial infarction and corresponds to ejection fraction\(^{45,46}\). As recently demonstrated after resting injection, regional activities of both \(^{201}\)Thallium and \(^{99}\)Tc-Sestamibi scintigraphy, as assessed by quantitative analysis, are similar in reversibly dysfunctional myocardium and irreversibly dysfunctional myocardium\(^{45,46}\). Therefore, the total amount of severely underperfused myocardium, as evidenced by resting \(^{201}\)Thallium-scintigraphy, should provide a reasonable estimate of myocardium unlikely to recover and thus of infarct extent. Also, our study did not provide any postmortem examinations. We therefore could not establish an exact correlation between changes in serum TNF-\(\alpha\) and gram of necrotic myocardium. On the other hand, it has been the purpose of the study to investigate the relationship of clinically frequently used parameters of myocardial injury and this novel sampling approach to assess the amount of irreversible myocardial damage.

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Conclusion

Delta-(TNF) provides valuable data about the extent of severely injured myocardium after acute myocardial infarction. In contrast to other enzymatic methods, only two blood samples are necessary to obtain Δ(TNF-α). Therefore, the number of expensive laboratory determinations can be markedly reduced. Additionally, the discomfort for the patient concerning frequent blood samples can be avoided. In contrast to other methods, localization of infarct does not influence the relationship between TNF-α and infarct extent. In summary, the advantages of Δ(TNF-α) include easy performance in clinical routine, reduction of blood samples and laboratory investigations, clinically relevant information about infarct extent and independence from infarct localization.

References


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