Research Article

Cardiotrophin-1 Induces Tumor Necrosis Factor α Synthesis in Human Peripheral Blood Mononuclear Cells

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Chronic heart failure (CHF) is associated with elevated concentrations of tumor necrosis factor (TNF) α and cardiotrophin-1 (CT-1) and altered peripheral blood mononuclear cell (PBMC) function. Therefore, we tested whether CT-1 induces TNFα in PBMC of healthy volunteers. CT-1 induced in PBMC TNFα protein in the supernatant and TNFα mRNA in a concentration- and time-dependent manner determined by ELISA and real-time PCR, respectively. Maximal TNFα protein was achieved with 100 ng/mL CT-1 after 3–6 hours and maximal TNFα mRNA induction after 1 hour. ELISA data were confirmed using immunofluorescent flow cytometry. Inhibitor studies with actinomycin D and brefeldin A showed that both protein synthesis and intracellular transport are essential for CT-1 induced TNFα expression. CT-1 caused a dose dependent nuclear factor (NF)κB translocation. Parthenolide inhibited both NFκB translocation and TNFα protein expression indicating that NFκB seems to be necessary. We revealed a new mechanism for elevated serum TNFα concentrations and PBMC activation in CHF besides the hypothesis of PBMC activation by bacterial translocation from the gut.

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1. Introduction

CHF is not only the failure of the heart to generate sufficient cardiac output, but is a multisystemic disorder with immune activation leading to increased concentrations of several cytokines [1].

In CHF several studies showed increased concentrations of proinflammatory cytokines such as TNFα, interleukin (IL)-1, IL-6, IL-18, and cardiotrophin-1 (CT-1) [2–5]. One of the most examined proinflammatory molecules in CHF is TNFα. TNFα is a trimeric 17-kDa polypeptide mainly produced by monocytes and macrophages. The effects of TNFα on cardiac function are concentration and time-dependent. Short-term TNFα expression is thought to be an adaptive mechanism; whereas prolonged expression causes left ventricular dysfunction and cardiomyopathy leading to CHF propagation. However, TNFα influences not only the heart itself but causes endothelial dysfunction and peripheral muscle wasting [6].

Cardiotrophin-1 (CT-1) is a member of the IL-6 cytokine family that consists of IL-6, IL-11, ciliary neurotrophic factor (CNTF), cardiotrophin-1 (CT-1), cardiotrophin-like cytokine (CLC), leukemia inhibitory factor (LIF), neuropoietin (NPN), and oncostatin M (OSM) and has recently been supplemented by the addition of two newly characterized cytokines: IL-27 and IL-31 [7]. All these cytokines bind to a specific receptor chain (IL-6R, IL-11R, or LIFR for CT-1, LIF, OSM). Following cytokine binding the cytokine/receptor complex associates with glycoprotein 130 (gp130) causing tyrosine phosphorylation of gp130 and the signal is transduced via the Janus kinase (JAK)/signal transducer and activation of transcription 3 (STAT3) pathway [8–10]. CT-1 is expressed in a time-dependent manner during embryogenesis of organs, is expressed in the heart during life, induces
2.2. Cell Culture.

Human peripheral blood mononuclear cells were obtained from healthy volunteers by Ficoll-paque centrifugation. The cells were washed three times with PBS, resuspended in RPMI 1640 supplemented with 10% fetal calf serum, and cultured in plastic dishes at 37 °C in a humified 5% CO₂ atmosphere. Cells were cultivated for 24 hours with RPMI 1640 supplemented with 10% fetal calf serum, 1% penicillin, streptomycin (all from Biochrom AG, Berlin, Germany), and cultured in plastic dishes at 37 °C in a humified 5% CO₂ atmosphere. Cells were cultivated for 24 hour with RPMI 1640 supplemented with 10% fetal calf serum, 1% penicillin, streptomycin. Afterwards, cells were subconfluent and medium was replaced by fresh medium. After 24 hours, over 90% of PBMC were alive tested by trypan blue exclusion. Stimulation and pharmacological studies were done afterwards.

Primary cultures from human vein endothelial cells were purchased from PromoCell (Heidelberg, Germany). Cell culture was done according to the manufacturer’s manual in endothelial growth medium with 2% fetal calf serum (EGM, PromoCell, Heidelberg, Germany). Cells were grown to confluence in collagen I coated tissue culture plastic (Becton Dickinson, Franklin Lakes, USA). Cells were used in the second to fifth cell passages.

All stimulants, inhibitors and media were without significant endotoxin levels according to the manufacturers’ instructions.

Pharmacological agents, dissolved in fresh medium, were added to the cells for defined time intervals and concentrations. As a control, fresh medium was added to the cells.

Approval for this study was given by the Ethics Committee of the Friedrich Schiller University of Jena, and subjects gave their written informed consent according to the university guidelines.

2.3. Real-Time PCR. Total RNA from cultivated PBMC was extracted according to the RNeasy protocol (Qiagen, Hilden, Germany). One µg of total RNA was reversely transcribed into cDNA in a volume of 20 µl with avian myeloma leukaemia virus (AMV) reverse transcriptase and oligo dT primers (Promega, Madison, USA) according to the manufacturers manual.

Real-time PCR measurement of TNFα cDNA was performed with the Light Cycler Instrument using the Fast Start DNA Master SYBR Green I kit (Roche Diagnostics, Mannheim, Germany). For verification of the correct amplification product, PCR products were analyzed on a 2% agarose gel stained with ethidium bromide. The specific primer for human TNFα was purchased from R&D Systems. The amplification program for TNFα consisted of 1 cycle of 94°C with a 4-minute hold followed by 40 cycles of 95°C with a 45-second hold, 59°C annealing temperature with a 45-second hold, and 72°C with a 45-second hold. The specific primer pair for GAPDH was: sense primer 5′ GG GAG TG TGG AG GTC GG 3′, antisense primer 5′ TGG ACT CCA CGT ACT CAG 3′. The amplification program for GAPDH consisted of 1 cycle of 95°C with a 30-second hold followed by 30 cycles of 95°C with a 5-second hold, 59°C annealing temperature with a 10-second hold, and 72°C with a 20-second hold. Each reaction (20 µl) contained 2 µl cDNA, 2.5 mM MgCl₂, 1 pmol of each primer, and 2 µL of Fast Starter Mix (containing buffer, dNTPs, Sybr Green dye and Taq polymerase). Amplification was followed by melting curve analysis to verify the correctness of the amplicon. A negative control without cDNA was run with every PCR to assess the specificity of the reaction. Analysis of data was performed using Light Cycler software version 3.5. PCR efficiency was determined by analysing a dilution series of cDNA (external standard curve). The identity of the PCR product was confirmed by comparing its melting temperature (Tm) with the Tm of amplicons from standards or positive controls. GAPDH was analyzed in parallel to each PCR and the resulting GAPDH values were used as standards for presentation of TNFα transcripts.

2.4. TNFα ELISA. Cultured PBMCs were treated with various concentrations of CT-1 for various time periods. TNFα concentrations in the culture supernatants were determined by ELISA (QuantiGlo, R&D Systems, Wiesbaden, Germany) according to the manufacturer’s instructions.

2.5. EMSA. Nuclear extracts were achieved by the EpiQuik Nuclear Extraction KIT I (Epigentek, NY, USA) according to the manufacturer’s manual. Afterwards, protein concentrations of nuclear extracts were determined according to the Bradford method. For determination of NFkB 2 µg of nuclear proteins were used and further analyzed by gel electrophoretic mobility shift assay (EMSA) according to the
suppliers manual. EMSA kits and probes were purchased from Panomics, Redwood City, USA.

2.6. Immunofluorescent Flow Cytometric Analysis of Cytokine Production. For intracellular staining peripheral blood was collected in lithium-heparin tubes. 100 μl of blood was added to RPMI-1640 medium including brefeldin A (final concentration: 1 μg/ml) (Sigma, Taufkirchen, Germany), and incubated for 6 hours time at 37°C. Next, erythrocytes were lysed by NH4Cl. After washing with PBS/2% FCS cells were stained with monoclonal antibodies against the surface antigens CD3 (Coulter-Immunotech, Krefeld, Germany), CD4 (Caltag, Hamburg, Germany) CD8 or CD14 (BD-Pharmingen, Heidelberg, Germany) (15 minute, RT), followed, after a washing step, by fixation with 100 μl 2% paraformaldehyde for 10 min at RT. After a wash the cells were incubated in 100 μl permeabilisation solution (0,1% saponin and 0,1%NaN3 in PBS) together with 1 μl directly conjugated anti-TNFα antibody (BD-Pharmingen, Heidelberg, Germany) for 15 minute at RT. Followed by a wash with permeabilisation solution the cells were resuspended in PBS/2% FCS and fluorescence intensity was analyzed by flow cytometry (FACSCalibur, Becton-Dickinson, Heidelberg, Germany). For analysis regions were defined by forward scatter and side scatter as well as CD3+/CD4+ or CD3+/CD8+-lymphocyte populations and CD14+ monocyte population. Data were analyzed with CellQuest Software.

2.7. Statistical Analysis. Because the amount of the cytokines produced was different in each experiment, the effects on TNFα production were normalized to unstimulated cells, which were set as one. Data were analysed by nonparametric methods to avoid assumptions about the distribution of the measured variables. Comparisons between groups were made with the Wilcoxon test. All values are reported as means ± SEM. Statistical significance was considered to be indicated by a value of P < .05.

3. Results

3.1. CT-1 Induces TNFα Protein and mRNA Levels in PBMC. In the first sets of experiments we analysed whether CT-1 is able to induce TNFα in PBMC. As shown in Figure 1(a), CT-1 induced in a concentration-dependent manner TNFα in the supernatant determined by a commercial available ELISA. Maximal TNFα concentration was found after 3 to 6 hours and declined afterwards reaching nearly control.
values after 24 hours, indicating that CT-1 causes only a transient TNFα release in PBMC. In the next experiments we determined intracellular TNFα protein in monocytes, CD4+ and CD8+ lymphocytes after stimulation with various concentrations of CT-1 in the presence of brefeldin A using immunofluorescent flow cytometry. Intracellular TNFα determination in CD4+ and CD8+ lymphocytes did not show an effect of CT-1 on TNFα expression (data not shown). In monocytes we found a concentration-dependent increase of intracellular TNFα after CT-1 application (Figure 1(b)). These results showed that CT-1 induced TNFα in PBMC independent of culture conditions and independent of determination methods.

On TNFα mRNA level we found maximal mRNA after 1 hour. Afterwards TNFα mRNA decreased (Figure 2). Blocking CT-1 by an antibody against CT-1 inhibited CT-1 induced TNFα mRNA (data not shown) indicating that TNFα induction is specifically caused by CT-1.

3.2. The Effect of CT-1 on TNFα Expression in PBMC Is Dependent on mRNA Synthesis and Intracellular Protein Transport. With the next experiments we addressed the question whether TNFα protein expression is dependent on mRNA synthesis and intracellular protein transport. In Figure 3 it is shown that both inhibition of mRNA synthesis by actinomycin D and intracellular protein transport by brefeldin A were able to abolish CT-1 induced TNFα protein induction in the supernatant. These results showed that CT-1 was responsible for new protein synthesis of TNFα protein. Furthermore TNFα protein was secreted into supernatant actively.

3.3. CT-1 Induces TNFα via NFκB. As shown in Figure 4 CT-1 caused a concentration-dependent NFκB translocation to the nucleus determined by EMSA reaching maximal translocation with 100 ng/ml CT-1.

In the next sets of experiments we used EMSA to verify that NFκB activation was responsible for CT-1 induced TNFα expression in PBMC. Human umbilical vein endothelial cells (HUVECs) stimulated with TNFα were used as a control. Unstimulated cells did not show significant NFκB protein in the nucleus; whereas CT-1 caused translocation of NFκB into the nucleus. Parthenolide, an inhibitor of NFκB activation, was able to inhibit NFκB translocation to the nucleus (Figure 5).

NFκB translocation is essential for TNFα expression as shown in Figure 6(a) and 6(b). Because parthenolide was able to inhibit TNFα expression both on protein and mRNA level we conclude that CT-1 not only was responsible for NFκB translocation to the nucleus but this translocation was responsible for TNFα expression. Using flow cytometry we found in monocytes an increase of intracellular TNFα after CT-1 application which could be inhibited by parthenolide (Figure 6(c)). Parthenolide alone did not show a significant effect on TNFα expression in unstimulated cells.
results show that CT-1 induced TNFα in PBMC independent of culture conditions and independent of determination methods and NFκB seems to be essential for the effect of CT-1 on TNFα induction in PBMC.

4. Discussion

The first result of our study is that CT-1 is able to induce TNFα mRNA and protein in PBMC of healthy volunteers.

TNFα is increased in serum of patients with CHF and correlates with the severity of heart failure, cachexia [20], and clinical outcome [21]. TNFα may be involved in progression of CHF because high levels of TNFα can induce left ventricular dysfunction, ventricular remodelling, cardiomyopathy, and pulmonary edema [22, 23].

Cultured human PBMC can synthesize and secrete TNFα. In heart failure, both the heart itself and activated monocytes are able to secrete TNFα [18, 24]. Furthermore, the capacity of PBMC of CHF patients to secrete TNFα is increased compared to control. Our data are in good agreement with these former studies and in opposite to Shimokawa et al. [25] who found decreased cytokine generation capacity of monocytes in severe heart failure after stimulation with lipopolysaccharide.

Besides the hypothesis that in CHF the failing heart itself is the main source of TNFα it is speculated by other groups that activated monocytes are responsible for increased TNFα serum concentrations. Monocytes may be activated by LPS from the gut because the barrier function of the gut by cardial edema is disturbed and bacteria can easily translocate from the gut lumen to the blood stream [26].

As a third possibility our data suggest at least in theory a new mechanism for TNFα production of PBMC in heart failure. CT-1 produced by the failing ventricle [27] is able to induce TNFα in PBMC without LPS. The here presented mechanism might also explain why TNFα may be still elevated in CHF even after edema were treated successfully with diuretics and the integrity of gut mucosa was restored. Furthermore, our data support the study of Petretta et al.

![Detection of NFκB activity in human PBMC. Representative EMSA of CT-1 induced NFκB activity in PBMC, which could be inhibited by parthenolide an inhibitor of NFκB activation. Human umbilical vein endothelial cells (HUVECs) stimulated with TNFα were used as control.](image)

![Figure 5: Detection of NFκB activity in human PBMC. Representative EMSA of CT-1 induced NFκB activity in PBMC, which could be inhibited by parthenolide an inhibitor of NFκB activation. Human umbilical vein endothelial cells (HUVECs) stimulated with TNFα were used as control.](image)

![Figure 6: Effect of parthenolide on CT-1 induced TNFα expression.](image)
who found that TNFα is not produced by the failing heart or the gut in patients with mild to severe heart failure.

The second result of our study is the fact that CT-1 activates the NFκB system in a concentration-dependent manner in PBMC of healthy volunteers. Our in vitro data are in line with studies that found an activation of the NFκB system in peripheral blood cells in CHF. Jankowska et al. reported an activation of the NFκB system in peripheral blood leukocytes in CHF patients measured by immunocytochemistry [29]. Siedienko et al. found an augmented activation of NFκB activation in blood mononuclear cells using electromobility shift assay in patients with CHF compared to healthy controls [30]. The exact pathway responsible for NFκB activation in CHF is still unknown and remains to be determined.

Our study has several limitations. We only used inhibitor experiments to characterise the pathway responsible. Furthermore we used a relative high parthenolide concentration. But within 3 hours, there is no cytotoxic effect as shown by O’Neill et al. in [31]. We also used high CT-1 concentrations compared to concentrations reported in patients with CHF by Ng et al. [12]. On the other hand a paper published in 2008 [32] reported serum CT-1 concentration in healthy controls and patients with metabolic syndrome of about 100 ng/ml. So far serum concentration of CT-1 in healthy controls and patients is a matter of discussion. But independent of reported CT-1 serum concentration the concentration of CT-1 should be much higher in the myocardium which is the source of CT-1 in CHF [33]. Exact intramyocardial CT-1 concentrations are not determined so far, only mRNA and immunohistochemical studies showed increased CT-1 in hearts of patients with CHF [34].

In our experiments both TNFα mRNA expression and TNFα protein production of PBMC showed a large standard variation. First one explanation for the large standard deviation may be a different genetic susceptibility of PBMC from different persons to stimuli [35]. Second, we used the low basal mRNA concentration as the basis of normalization explaining the large standard variation. Third, the fact that the increase of TNFα mRNA expression after CT-1 application is much higher compared to the increase of protein in the supernatant may be explained methodically.

We used PBMC of healthy volunteers to examine the effect of CT-1 in CHF. Because in CHF many proinflammatory cytokines are elevated and PBMC are activated, it is not easy to study the effect of a single cytokine in PBMC of patients with CHF. For this reason we used PBMC from healthy volunteers in culture and stimulated them with recombinant CT-1.

In conclusion, our study offers a new mechanism of increased serum TNFα concentrations in heart failure. Interestingly, in our study LPS is not needed for elevated TNFα expression in PBMC. Elevated TNFα concentrations may be important in the pathogenesis and perpetuation of heart failure by modulating systemic metabolism, causing apoptosis and having a negative inotropic effect [36]. In the light of our results modulating CT-1 may be an interesting pharmacological target in the treatment of CHF.

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