A Human Tumor Necrosis Factor (TNF) α Mutant That Binds Exclusively to the p55 TNF Receptor Produces Toxicity in the Baboon

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Summary

A number of recent studies have demonstrated that cellular responses to tumor necrosis factor (TNF) mediated by the p55 and the p75 TNF receptors are distinct. To evaluate the relative in vivo toxicities of wild-type TNFα (wtTNFα) and a novel p55 TNF selective receptor agonist, healthy, anesthetized baboons (Papio sp.) were infused with a near-lethal dose of either wtTNFα or a TNFα double mutant (dmTNFα) that binds specifically to the p55, but not to the p75, TNF receptor. Both wtTNFα and dmTNFα produced comparable acute hypotension, tachycardia, increased plasma lactate, and organ dysfunction in Papio. However, administration of wt TNFα produced a marked granulocytosis and loss of granulocyte TNF receptors, whereas little if any changes in neutrophil number or cell surface TNF receptor density were seen after dmTNFα mutant administration. Infusion of dmTNFα resulted in a plasma endogenous TNFα response that peaked after 90-120 min. We conclude that selective p55 TNF receptor activation is associated with early hemodynamic changes and the autocrine release of endogenous TNFα. Significant systemic toxicity results from p55 TNF receptor activation, but the role of the p75 TNF receptor in systemic TNF toxicity requires further study.

TNFα is a pleiotropic cytokine with varying immunologic and inflammatory host defense activities. The in vitro actions of TNFα include cytotoxicity of some tumor cell lines, antiviral activity, fibroblast and lymphocytic cell proliferation, and endothelial cell activation (for a review see reference 1). In certain transplantable tumors in mice, TNFα causes hemorrhagic necrosis in vivo (2). Because of its potential as an antineoplastic agent, recombinant TNFα has been administered to patients with malignancies in several clinical trials. Whereas systemic administration of >200 μg/m² of TNFα has not produced the expected potent and general antitumor activity (3), such infusions were found to produce unwelcome fever and hemodynamic changes (4). Similarly, when administered to experimental animals in relatively greater quantities, TNFα induced shock and mortality (5, 6). The continued interest in the antitumor activity of TNFα is supported by the results obtained with high-dose, TNFα perfusions combined with a chemotherapeutic agent (7).

Recent reports on cellular studies have suggested that binding of TNFα to its two cellular receptors, p55 and p75, elicits distinct biological responses. For example, human umbilical vein endothelial cells express both TNF receptor types, but TNFα-induced cell adhesion and expression of intercellular adhesion molecule 1, E-selectin and vascular cell adhesion molecule 1 were found under exclusive p55 receptor control (8). TNF binding to p55 TNF receptor also confers antiviral activity in hepatocytes and IFN-γ primed fibroblasts (9). Tartaglia et al. (10) reported that p55 mediated apoptosis in sensitive cell lines and induced manganese superoxide dismutase, whereas p75 activated thymocyte proliferation and generation of cytotoxic T cells.

Controversy exists whether the shock responses to TNFα in vivo are mediated by binding to p55 or p75. Historically, the relatively low systemic toxicity of human TNFα in mice has been attributed to the fact that human TNFα only binds the mouse p55 TNF receptor (11, 12). The lethal dose of
human TNFα in the mouse is in excess of 1 mg/kg body weight (BW), whereas murine TNFα causes death with doses as low as 10 μg/kg BW (13). Thus, a TNFα agonist that binds to p55 but not p75 in humans might produce less pronounced systemic toxicity than wild-type TNFα (wtTNFα), while retaining antitumor and antiviral activities. Van Ostade et al. (14) have recently shown that a mutant TNFα exclusively binding to the human p55 receptor has antitumor activity against a sensitive human tumor cell line growing as a solid tumor in nude mice without any associated toxicity. However, recent studies using p55-deficient mice showed that TNF binding to p55 was required for its systemic toxicity (15, 16).

Here we present a study of the relative in vivo toxicity in baboons of human wtTNFα compared with that of a TNFα mutant which binds with wild-type activity to human p55, but does not bind to p75. This TNFα mutant was previously generated by introducing two point mutations replacing Arg32 by Trp, and Ser56 by Thr (identified as a double mutant TNFα [dmTNFα]) (17). dmTNFα also binds selectively to the baboon p55, but not to p75, whereas wtTNFα binds to both baboon TNF receptors. When administered to healthy Papio at a dose of 100 μg/kg BW, dmTNFα and wtTNFα produced comparable cardiovascular disturbances and tissue injuries. These data demonstrate that the p55 TNF receptor has an important role in systemic TNF toxicity.

Materials and Methods

The generation of a dmTNFα mutant specific for the human p55 receptor has been reported (17). wtTNFα and dmTNFα were purified by sequential gel filtration (Q-Sepharose, Pharmacia, Uppsala, Sweden) and ion exchange chromatography (Mono-S; LKB-Pharmacia) as described in reference 17 to yield an electrophoretically pure protein preparation. The identity of the TNFα preparations was confirmed by amino acid composition analyses or ion spray mass spectrometry. Samples were diluted in sterile, endotoxin-free, physiologic saline to a final concentration of 500 μg/ml. Endotoxin content of the final preparations was <14 EU/mg protein. Solid-phase Radioligand Binding Assay. To demonstrate that receptor type specificities of the human wild-type TNFα and mutant TNFα were maintained in Papio, solid-phase radioligand binding studies were performed. HL60 cells were cultured and lysed with Triton X-100 as previously described (18). Baboon buffy coats were obtained from 100 ml of venous blood from Papio antiaggregated with EDTA; cells were subsequently pelleted and frozen at −70°C. Cell pellets containing ~10^9 leukocytes were resuspended in 1.0 ml of PBS, pH 7.4, containing a cocktail of protease inhibitors (19) and diluted with an equal volume of the same buffer containing 2% Triton X-100. After extraction overnight at 4°C, the samples were clarified by centrifugation and immediately used for radioligand binding assay or stored at −80°C.

96-well microtiter plates were coated with affinity-purified polyclonal antibodies (10 μg/ml in PBS) raised against recombinant soluble human p55 and p75 (8). After blocking with 1% defatted milk powder in 50 mM Tris, 140 mM NaCl, 5 mM EDTA, 0.001% Karbox MW/WT for 1-2 h at room temperature, HL60 cell extract (2.3 × 10^6 cells/ml) or baboon buffy coat extract (5 × 10^8 leukocytes/ml) were added (100 μl/well) and incubated overnight at 4°C. The wells were then incubated with 15 ng/ml human 125I-TNFα (sp act 0.3-1.0 × 10^6 cpm/μg (19)) in blocking buffer containing 0.1% defatted milk powder in the presence or absence of 3 μg/ml unlabeled human wtTNFα or dmTNFα mutant. Incubation at room temperature for 4 h, the amount of 125I-TNFα bound to each well was determined in a Phosphoimager® (Molecular Dynamics, Inc., Sunnyvale, CA).

Treatment of Experimental Animals. Nine young adult male and female Papio sp baboons were purchased from Southwest Foundation for Biomedical Research (San Antonio, TX). All animals were quarantined for a minimum of 2 wk at the Research Animal Resource Center of Cornell University Medical College (CUMC) to confirm their good health and lack of disease transmissible to humans. The experimental protocol was approved by the Institutional Animal Care and Use Committee at CUMC.

Study Protocol. After an overnight fast, animals were initially anesthetized with ketamine (10 mg/kg intramuscularly) and anesthesia was thereafter maintained by intravenous administration of sodium pentobarbital at 3-5 mg/kg BW/h i.v. The animals were instrumented for invasive monitoring as described previously (20, 21). After baseline blood sampling and a waiting period of at least an hour to allow equilibration, 100 μg/kg BW of either wtTNFα (n = 3) or dmTNFα (n = 3) were administered via the femoral vein as a bolus injection. An additional three baboons received no injections and served as instrumented controls. Arterial blood samples were obtained at 0.5, 1, 3, 5, 10, 15, 30, 60, 90, and 120 min, at hourly intervals through 8 h, and again at 24, 48, and 96 h for pharmacokinetic and blood chemistry analyses. The investigators caring for the animals were blinded to treatment. Leukocyte and thrombocyte counts were measured on venous blood anticoagulated with EDTA by flow cytometric, light scatter, and Coulter counter analyses, respectively, as previously reported (20). Prothrombin and partial thromboplastin times were measured by the clinical laboratories at the Animal Medical Center (New York). TNF receptor on granulocytes were quantitated by cytofluorimetry using biotinylated TNFα and PE-conjugated streptavidin. Briefly, baboon blood was anticoagulated with Na-EDTA. Erythrocytes were lysed with a bicarbonate-buffered (pH 7.2) ammonium chloride solution. Leukocytes were recovered by centrifugation and washed with PBS containing 0.1% sodium azide (PBS-A). Specific staining was determined with 1.0 μg/ml biotinylated, human TNFα whereas nonspecific staining was determined with biotinylated TNFα plus 100-fold excess, unlabeled human TNFα. After incubation on ice for 15 min, cells were washed with PBS-A and incubated with 0.5 μg/ml streptavidin-conjugated PE for 15 min on ice. Cells were then washed and resuspended in PBS-A for flow cytometric analysis. For each experiment, the flow cytometer photomultiplier gain was standardized using a single lot of PE-conjugated beads. Mean channel fluorescence (>570 nm) of forward and side angle light scatter-gated granulocytes was assessed. Data were presented as the difference (linear units) between mean channel fluorescence intensities of specifically and nonspecifically stained cells.

The plasma fraction of additional EDTA and heparinized samples was separated by centrifugation at 4°C and stored at −70°C until assayed for TNFα and TNFR I (p55) immunoactivity, as previously described (20, 21). TNFα bioactivity was determined using
the murine WEHI clone 13 cytotoxicity assay (21). IL-6 bioactivity (R9 hybridoma proliferation) and IL-8 immunoactivity were also assayed (20, 21). At the end of an 8-h monitoring period, all catheters were removed, and animals were awakened and returned to their cages. Blood was sampled at 24, 48, and 96 h. After the last blood sampling, baboons were sacrificed by the intravenous administration of 65 mg/kg sodium pentobarbital. Necropsy was performed at death, and tissues were fixed in 10% buffered formalin for light microscopy.

Statistical Analyses. Values are presented as the mean ± standard error. Differences in responses between baboons administered wild-type and mutant TNFα were analyzed by two-way analysis of variance. In some cases, differences from baseline were analyzed by one-way analysis of variance, and Dunnett's multiple range test. Significance was determined at the 95% level of confidence employing a one-tailed test.

Results

Specificity of TNFα Mutant in Papio. To test whether receptor-type selectivity for p55 of dmTNFα was maintained in baboons, the competitive binding of wtTNFα and dmTNFα to p55 and p75 TNF receptors derived from a human cell line and from Papio leukocytes was compared. Detergent-extracted receptors from both species were immobilized on a solid-phase coated with receptor-type-specific polyclonal antibodies that had been raised in rabbits against recombinant human receptors and that cross-reacted with the respective baboon receptors. As shown in Fig. 1, binding of 125I-labeled wtTNFα to the immobilized human and Papio p55 TNF receptors was competitively inhibited by unlabeled wtTNFα or dmTNFα, whereas binding to the p75 receptors of both species was competed by wtTNFα but not by dmTNFα.

Papio Cardiovascular and Physiologic Responses. Administration of 100 μg/kg BW of human wtTNFα produced significant hypotension and tachycardia in the anesthetized baboon (Fig. 2). Cardiac output declined (data not shown) and

Figure 1. Competitive binding of human wtTNFα and dmTNFα mutant to human and baboon p55 and p75. Solubilized human and baboon TNF receptors were captured on microtiter plates by coating the wells with polyclonal antibodies specific for human p55 and p75. Binding of human wild-type 125I-TNFα to the TNF receptors was determined in the presence or absence of excess unlabeled wtTNFα or dmTNFα mutant. The amount of radioactivity bound in the absence of competitor is taken as 100% and was 24,911 and 74,383 counts for the p55 from baboon PBMC and HL60 cells, respectively, and 11,077 and 20,587 counts for the p75 from baboon PBMC and HL60 cells, respectively. (Top) Binding competition to p55 (receptors from both species immobilized by antihuman p55 antibodies); (bottom) binding competition to p75 (receptors from both species immobilized by anti-human p75 antibodies).

Figure 2. Hemodynamic and body temperature changes in baboons treated with 100 μg/kg BW of either wtTNFα or dmTNFα. (Top) Heart rate (middle), mean arterial pressure, and (bottom) core temperature were all measured as described in Materials and Methods. Administration of both TNFα molecules resulted in a significant tachycardia and falls in mean arterial pressure and cardiac output. The difference in increase in core temperature in baboons treated with wtTNFα and dmTNFα was statistically significant.
a significant rise in blood lactate concentrations was also evident (Table 1). The animals also developed a pyrexic response. Although none of the animals administered wtTNFα expired over the subsequent 4 d, significant organ dysfunction was observed. For example, serum creatinine and blood urea nitrogen (BUN) concentrations markedly increased over 48 h in the TNFα-treated animals indicating impairment of renal function (Table 1). In addition, concomitant increases in hepatic enzyme levels (serum glutamate-oxaloacetate transaminase [SGOT], serum glutamate-pyurate transaminase [SGPT]) were consistent with acute hepatocellular damage. The baboons receiving wtTNFα also developed a significant plasma IL-6 and IL-8 response.

Administration of dmTNFα at 100 μg/kg BW produced comparable degrees of hypotension and tachycardia; however, the pyrexic response was significantly less pronounced (Fig. 2). The elevation of blood lactate and presence of renal and hepatic dysfunction were similar between the animals treated with wtTNFα and with dmTNFα in the initial phase of the study, but these dysfunctions tended to be more protracted in the animals treated with dmTNFα. One of the three animals treated with dmTNFα became unresponsive and moribund after 48 h, and was euthanized because of animal welfare concerns.

Sham infusions had no effect on hemodynamic responses in healthy baboons (Fig. 2), nor were there any observed changes in measures of organ function (data not shown).

**Hematopoietic Responses.** Administration of the wtTNFα produced a significant granulocytosis (p<0.05 at 1, 3, 4, and 5 h versus baseline; Fig. 3). Blood monocyte and lymphocyte numbers rapidly declined (data not shown). Despite this granulocytosis, there was an almost complete loss of total cellular TNF receptors from blood granulocytes (Fig. 3). Unfortunately, because of the lympho- and monocytopenia induced by the TNFα administration, there were insufficient numbers to perform flow cytofluorometric analysis of TNF receptors upon these cells. Platelet counts declined from about 300,000/μl^3 to 100,000–150,000/μl^3 24–48 h after wtTNFα treatment, although prothrombin and partial thromboplastin times were only modestly affected (data not shown).

In baboons administered dmTNFα, granulocytosis was not observed. In addition, TNF receptors on granulocytes declined only transiently and then rapidly returned to levels comparable to baseline, suggesting an important role for p75 TNF receptor in receptor shedding. Baboons treated with the dmTNFα exhibited a similar monocytopenia and lymphopenia as seen in animals treated with wtTNFα. The soluble TNF p55 receptor concentrations increased in baboons treated with both wtTNFα and dmTNFα, although concentrations were marginally higher in baboons treated with wtTNFα. Adminis-

### Table 1. Biochemical Parameters in Baboons Treated with 100 μg/kg BW wtTNFα or dmTNFα

<table>
<thead>
<tr>
<th>Parameter</th>
<th>wtTNFα</th>
<th></th>
<th></th>
<th></th>
<th>dmTNFα</th>
<th></th>
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<tr>
<td></td>
<td>0</td>
<td>8</td>
<td>24</td>
<td>48 h</td>
<td>0</td>
<td>8</td>
<td>24</td>
<td>48 h*</td>
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<tr>
<td>Lactate</td>
<td>mg/dl</td>
<td>4.2 ± 0.7</td>
<td>40.6 ± 14.5</td>
<td>35.5 ± 7.8</td>
<td>24.0 ± 0.6</td>
<td>5.5 ± 0.9</td>
<td>27.9 ± 1.4</td>
<td>118 ± 43.7</td>
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<tr>
<td>BUN</td>
<td>mg/dl</td>
<td>14.2 ± 0.7</td>
<td>15.8 ± 2.1</td>
<td>32.6 ± 9.1</td>
<td>37.4 ± 12.5</td>
<td>15.8 ± 4.8</td>
<td>13.6 ± 3.2</td>
<td>34.0 ± 8.8</td>
</tr>
<tr>
<td>Creatinine</td>
<td>mg/dl</td>
<td>0.8 ± 0.1</td>
<td>1.2 ± 0.1</td>
<td>2.0 ± 0.5</td>
<td>1.7 ± 0.4</td>
<td>1.0 ± 0.1</td>
<td>1.3 ± 0.1</td>
<td>2.7 ± 0.4</td>
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<td>SGOT</td>
<td>IU/ml</td>
<td>28 ± 6</td>
<td>100 ± 24</td>
<td>332 ± 31</td>
<td>156 ± 34</td>
<td>30 ± 4</td>
<td>57 ± 11</td>
<td>244 ± 39</td>
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<tr>
<td>SGPT</td>
<td>IU/ml</td>
<td>28 ± 8</td>
<td>56 ± 17</td>
<td>274 ± 36</td>
<td>227 ± 44</td>
<td>29 ± 11</td>
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<td>IL-6, B.9 ng/ml</td>
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<td>26.9 ± 4.7</td>
<td>ND</td>
<td>ND</td>
<td>0 ± 0</td>
<td>21.9 ± 2.1</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>IL-8, ng/ml</td>
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<td>ND</td>
<td>0 ± 0</td>
<td>19.9 ± 3.5</td>
<td>ND</td>
<td>ND</td>
</tr>
</tbody>
</table>

* One baboon (No. 92-150) that received the dmTNF was euthanized at 48 h because of animal welfare concerns. The animal was unresponsive, and could not adequately eat or drink.

1 p<0.05 versus baseline (time zero) by one-way analysis of variance, and Dunnett's multiple range test.
Total Granulocyte Number

- $18000$
- $12000$
- $9900$
- $6000$
- $3000$
- $1500$
- $750$
- $0$

Granulocyte TNFR's

- $25$
- $20$
- $15$
- $10$
- $5$
- $0$

Specific NGF-Background WCF (linear units)

sTNFR I Concentrations

- $12000$
- $9000$
- $6000$
- $4000$
- $2000$
- $1000$
- $500$
- $0$

Time In Hours

- $1$
- $2$
- $3$
- $4$
- $5$
- $6$
- $7$
- $8$

Figure 3. (Top) Total granulocyte numbers, (middle) granulocyte TNF receptor activity, and (bottom) soluble TNF receptor I concentrations. Administration of either wtTNF or dmTNF resulted in increased soluble TNF p55 receptor concentrations, as determined by immunoassay. Infusion of wtTNF, but not dmTNF, resulted in a sustained loss of granulocytic cellular TNF receptors (*, p <0.05, one-sided test).

Histological Examination. Treatment of baboons with wtTNF produced a similar thrombocytopenia as seen with wtTNF, and had no significant effect on either prothrombin or partial thromboplastin times (data not shown).

Instrumentation and the sham procedure had no effect on hematologic parameters (data not shown).

Histological Examination. Treatment of baboons with wtTNF produced only modest histopathologic changes, including hepatic edema in one animal. In the three baboons treated with dmTNF, mild hepatic edema was also noted. Furthermore, in the one dmTNF-treated baboon that was euthanized for animal welfare concerns, moderate necrosis and hemorrhage of the spleen and adrenals was also observed, as well as some neutrophil margination and pooling in the lungs.

TNF Pharmacokinetics. The apparent $\beta$-phase half-life of dmTNF produced a similar thrombocytopenia as seen with wtTNF, and had no significant effect on either prothrombin or partial thromboplastin times (data not shown).

Instrumentation and the sham procedure had no effect on hematologic parameters (data not shown).

Histological Examination. Treatment of baboons with wtTNF produced only modest histopathologic changes, including hepatic edema in one animal. In the three baboons treated with dmTNF, mild hepatic edema was also noted. Furthermore, in the one dmTNF-treated baboon that was euthanized for animal welfare concerns, moderate necrosis and hemorrhage of the spleen and adrenals was also observed, as well as some neutrophil margination and pooling in the lungs.

wtTNF immunoactivity in Papio was 81 min (Fig. 4). The half-life of wtTNF bioactivity, as determined by the WEHI cytotoxicity assay, was comparable. In contrast, the dmTNF mutant had an apparent $\beta$-phase half-life that was significantly longer, ~169 min. Previous in vitro studies have shown that this dmTNF does not bind to the murine p55, although its affinity for human p55 is not different than wtTNF's affinity for p55 (16). Thus, incubation of dmTNF with the murine WEHI clone 13 cell does not induce cytotoxicity. However, when dmTNF was infused into otherwise healthy baboons and plasma from such animals was coincubated with WEHI clone 13 cells, cytotoxicity was observed in plasma 90-120 min later (Fig. 4, bottom). Since dmTNF is not bioactive in this assay, cytotoxicity must have resulted from another source. Coincubation of these plasma samples with either a mAb directed against human TNF (mAb 18.1.2) or a chimeric p55, human IgG fusion protein (22), completely
eliminated this cytotoxicity (data not shown), confirming that the plasma appearance of WEHI cytotoxicity was endogenous TNFα.

Discussion

In this study, administration of recombinant human TNFα at a dose of 100 μg/kg BW to the healthy baboon (Papio) produced a 35% fall in mean arterial pressure, tachycardia, and evidence of both renal and hepatic dysfunction. These responses are key elements of systemic TNF toxicity and have also been observed in cancer patients receiving TNFα as an antitumor agent (4). In dogs receiving comparable doses of TNFα, irreversible tissue damage and mortality have also been reported (6).

Healthy baboons treated with the same dose of the p55-specific dmTNFα responded similarly in several respects. For example, the hemodynamic changes and organ damage were of similar magnitude in both groups of animals. In fact, one mutant TNFα-treated baboon had to be euthanized, because the animal was unresponsive and unable to eat and drink. The binding studies confirm that dmTNFα competes with wtTNFα for Papio p55, but not for p75. Thus, it must be concluded that the systemic toxicity of dmTNFα in Papio is a result of its binding to the baboon p55 receptor exclusively.

The more protracted signs of organ dysfunction and the histological changes in the animals treated with dmTNFα could be the consequence of its longer pharmacologic half-life which translates into a higher persistent dose at the later phases of the experiment. The reasons for the different half-lives of wtTNFα and dmTNFα are not understood, but the present results are consistent with a significant role for p75 and its soluble form in TNFα elimination, which might be correlated with the role of p75 in TNF receptor shedding.

One novel observation of this study was that infusion of dmTNFα induced an endogenous, circulating TNFα response. It is unlikely that the minute contamination of dmTNFα with endotoxin (14 EU/mg protein) can explain the endogenous TNFα response. The baboon is the most endotoxin-resistant of all nonhuman primates (23), and our previous studies have demonstrated that 500 μg/kg BW of Salmonella typhosa LPS is required to produce a 1 ng/ml TNFα plasma response (24), whereas the current animals received only ~150 pg/kg BW.

However, the present studies cannot exclude entirely the possibility that toxicity induced by dmTNFα was secondary to the endogenous TNFα response. The toxicity seen is clearly due to the p55 agonist, but it cannot be distinguished whether these responses are the direct result of dmTNFα binding to p55 or are the result of the induced endogenous TNFα that subsequently binds to both p55 and p75. The onset of hypotension and hemodynamic disturbances was not delayed in animals treated with dmTNFα, relative to those animals receiving wtTNFα, as might have been expected if the changes were due to endogenous TNFα production. Nevertheless, the present studies do not distinguish rigorously between responses due to exogenous dmTNFα administration and endogenous TNFα because of the variability in the onset of clinical symptoms or signs. Furthermore, if p55 receptors were fully occupied by dmTNFα, then endogenous baboon TNFα is competed at p55 and would bind with some preference to the p75 receptor. Thus, the relatively low concentrations of endogenous TNFα might have disproportionate activities and elicit toxic host responses equivalent to higher TNFα concentrations.

Based on in vitro studies, distinct functions have been attributed to TNFα binding to these two TNF receptor types in various cells. However, the significance of TNFα in vivo, like that of other cytokines, cannot be easily deduced from individual tissue responses, but rather, should be understood from its integrated actions on the complex assembly of cells and organ systems in a living organism. The systemic toxicity of TNFα, as reflected in hemodynamic changes and organ dysfunction, is undoubtedly the sum of responses by different cells in various organs.

It has been proposed from the differing toxicities of mouse and human TNFα in mice that p55 selective agonists can be expected to have a lower systemic toxicity than wild-type TNFα. This hypothesis has not been confirmed in this study. In fact, the results of this study are more consistent with the conclusion of Pfeffer et al. (15) who demonstrated that p55-deficient mice sensitized with D-galactosamine were tolerant of endotoxic shock. Furthermore, Rothe et al. (16) demonstrated that p55-deficient mice are insensitive to TNF toxicity, although they remain susceptible to the lethal effects of LPS in the absence of D-galactosamine sensitization. Finally, the fact that TNFα induction of endothelial cell adhesion molecules, which must be considered part of systemic toxicity, is under dominant p55 control (8) also argues that p55 selective agonists cannot be completely devoid of systemic toxicity.

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References