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Comparison of the effects of recombinant interleukin 6 and recombinant interleukin 1 on nonspecific resistance to infection

Interleukin 1 (IL1) is a potent enhancer of nonspecific resistance to infection in mice. Since IL1 also induces interleukin 6 (IL6), we tested the hypothesis that IL6 mediates the effect of IL1 on nonspecific resistance. In a lethal Pseudomonas aeruginosa infection in granulocytopenic mice, in which 80 ng of recombinant human IL1α protects against death, IL6 appeared to be much less effective. Dosages of 8 ng, 80 ng and 320 ng IL6 did not differ from the control, whereas 800 ng had a marginal protective effect (0.05 < p < 0.1). IL1 and IL6 did not potentiate each other in animals treated with suboptimal dosages of both cytokines. Numbers of bacteria cultured from the blood, thigh muscle, liver, spleen, and kidney were similar in animals treated with 800 ng IL6 and in control animals, arguing against activation of microbicidal mechanisms. The serum concentration profile of IL6 after an i.p. injection of 80 ng IL1 was similar to that after 80 ng IL6 i.p. Only minute amounts of IL1 were detected in serum after an i.p. injection of IL6. Taken these data together, it appears that increased resistance to infection induced by IL1 is not mediated by IL6.

1 Introduction

Recently, we have reported the beneficial effect of recombinant interleukin 1 (rIL1) on survival of granulocytopenic mice with a lethal Pseudomonas aeruginosa infection [1]. In this study, we found protection with a single low dosage of IL1. Although we could demonstrate that protection was not due to a direct antimicrobial effect of IL1, to granulocytes or to activation of macrophages, we were unable to elucidate the mechanisms of protection against lethal P. aeruginosa infection. One hypothesis was that treatment with IL1 protected against the lethal effects of the lipopolysaccharide (LPS) or other toxins of P. aeruginosa. In a subsequent study, in which the effect of IL1 on a candidal infection in neutropenic mice was investigated, we could demonstrate that the effect of IL1 on survival is not limited to Gram-negative infection [2].

IL6 is a 26-kDa cytokine, which is produced by mononuclear phagocytes, fibroblasts and a variety of other types of cells [3-5]. This factor has been described as interferon-β2 [6], hybridoma (plasmocytoma) growth factor [7-9], B cell-stimulating factor 2 (BSF-2) [10] and hepatocyte-stimulating factor [11]. Since IL1 is a potent inducer of IL6, the latter could be responsible for the enhanced survival of animals treated with IL1, e.g., by inducing a hepatic acute-phase protein. Therefore, we have compared the effects of IL6 and IL1 on survival of lethally infected mice. In addition, we have investigated the kinetics of injected IL6 and IL1, and the mutual induction of these cytokines in vivo.

2 Materials and methods

2.1 Mice

Female, 25 g Swiss Webster mice (Broekman, Someren, The Netherlands), were fed standard laboratory chow and water ad libitum.

2.2 IL

Human recombinant IL1α (rIL1α), which was kindly provided by Dr. Peter Lomedico, Hoffmann-La Roche, Nutley, NJ, was used in the majority of the experiments. rIL1β (kindly provided by Dr. Alan Shaw, Biogen/Glaxo, Geneva, Switzerland) was also used. These IL1 preparations contained <30 pg lipopolysaccharide (LPS) per mg of protein. Human rIL6, containing <3 pg LPS/μg of protein was produced as published elsewhere [8].

IL1 and IL6 were given as a single i.p. injection in 2% (v/v) normal mouse serum in 0.1 ml pyrogen-free saline. Control mice received heat-inactivated IL1 (100°C for 20 min).

2.3 Infection model

Mice were rendered granulocytopenic (<0.5 x 10^n granulocytes per liter) by means of two i.p. injections of cyclophosphamide (Bristol Myers, Syracuse, NY), 150 and 100 mg/kg of body weight, respectively, 4 days and 1 day before the inoculation of the microorganism. Approximately 2 x 10^7 Pseudomonas aeruginosa (27853, ATCC, Rockville, MD) were injected into the left thigh muscle. Two doses of gentamycin (Lyomed Inc., Rosemont, IL), 120 mg/kg, were given s.c., 6 and 23 h post infection [1]. The mice in each cage were randomized to receive either IL1, IL6 or heat-inactivated IL1, 24 h before the inoculation of bacteria. Survival was...
over a period of at least 48 h. Survival curves were analyzed using the Kaplan Meier log rank test [12].

### 2.4 Clearance of bacteria

Twenty-four hours after the injection of *P. aeruginosa*, six mice treated with IL6 and six control mice were killed by CO₂ asphyxia. Immediately after death, blood cultures were taken by cardiac puncture, and the muscles of the left thigh (the site of inoculation of the bacteria), the spleen, the kidney and the liver were removed aseptically, weighed and homogenized in sterile saline in a tissue grinder. To bring the counts into the optimal range for reading, samples of thigh muscle were diluted 1:10⁴ and other samples were diluted 1:10 in sterile saline. The suspensions were then plated on sterile DST agar (Oxoid, Ltd., Basingstoke, GB) in tenfold dilutions After overnight incubation at 37°C the number of colonies was counted.

### 2.5 Pharmacokinetics of rIL6 and rIL1, and induction of IL6 by IL1

At various time points after an i.p. injection of 80 ng of IL6, three mice were killed by CO₂ asphyxia. Immediately after death blood was taken by cardiac puncture. The IL6 concentrations in the sera obtained were measured using the B-9 cell line [5], and IL1 concentrations were measured using D10.G4.1 cells [13], the D10(N4)M subclone; both assays have been described in detail [14]. Similarly, serum concentrations of IL6 and IL1 were measured after an i.p. injection of 80 ng IL1α in mice.

### 3 Results

#### 3.1 Survival of mice

Human rIL1α, given as a single i.p. injection of 80 ng (= 3 µg/kg) 24 h before infection, improved the survival of neutropenic mice with a lethal *P. aeruginosa* infection significantly ($\chi^2 = 6.8; p < 0.01$) compared to control mice that received heat-inactivated IL1 (Fig. 1). rIL6 was much less effective than IL1 in these protection experiments (Fig. 1). Even the effect of 800 ng IL6 was not significantly different from the control ($\chi^2 = 3.0; 0.05 < p < 0.1$); dosages of 320 ng, 80 ng and 8 ng did not differ from the control.

To investigate whether IL1 and IL6 would potentiate each other, suboptimal dosages of both cytokines (8 ng and 80 ng, respectively) were injected either alone or in combination (Fig. 2). No potentiation was detected; if anything, there was slight, albeit not significant antagonism between IL1 and IL6.

#### 3.2 Clearance of *P. aeruginosa*

No differences in the numbers of bacteria in blood and tissues were found between mice treated with 800 ng IL6 or control mice 24 h after an i.m. injection of $2 \times 10^7$ *P. aeruginosa* (Fig. 3). When the data were expressed as number of microorganisms per gram of tissue rather than per organ, the data from two groups also did not differ.

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Figure 1. The effect of IL1α and of IL6 treatment on the survival of granulocytopenic mice with a *P. aeruginosa* infection. The cytokines were given as single i.p. injections 24 h before infection. Control mice received heat-inactivated IL1 (100°C for 20 min). Only the difference in survival between animals treated with IL1 is significant ($p < 0.01$). Each group consisted of 20 mice.

Figure 2. The effect of 8 ng IL1α and 80 ng IL6 injected i.p. 24 h before infection, either alone or in combination, on survival of lethally infected mice. There is no potentiation of IL1 and IL6. Only the difference between survival with 8 ng IL1 and that of the control mice is significant at $p < 0.025$. Each group consisted of 22 mice.
Effects of IL 6 and IL 2 on infection

Min 3 0 l 90


The next question we addressed was whether IL1 and IL 6
of 80 ng IL1 are quite similar to those after an injection of the
6 could indeed demonstrate that IL 1 is a potent inducer of IL
6 together, the hypothesis mentioned above has to be refuted.

4 Discussion

In the present study, we have investigated the hypothesis that
IL 6 is the central mediator of IL 1-induced protection against
lethal bacterial infection in mice. The experiments show that
IL 6 is 10–100 times less potent than IL 1 in protecting mice. If
IL 1 induced a large amount of IL 6 in vivo, these results still
would not rule out an IL 6-mediated pathway. Although we
could indeed demonstrate that IL 1 is a potent inducer of IL 6
in mice, the serum concentrations of IL 6 after an i.p. injection
of 80 ng IL 1 are quite similar to those after an injection of the
(barely protective) 80 ng dose of IL 6 i.p. Taking these data
together, the hypothesis mentioned above has to be refuted.

The next question we addressed was whether IL 1 and IL 6
would potentiate each other. Using suboptimal dosages of
each cytokine, we could not detect any synergism. However,
the 800-ng dose of IL 6 had some protective effect, and these
results are reminiscent of experiments with tumor necrosis fac-
tor (TNF), in which a similar high dose was needed to find
some protection [15, 16]. Since we observed that IL 6 does
induce minute amounts to IL 1 in vivo, the protection by IL 6
might be mediated via IL 1.

The actual mechanism responsible for increase in survival
induced by IL 1, IL 6 and TNF remains unclear. In our previ-
ous studies direct antimicrobial effects of IL 1 were ruled out
in vitro [1, 2]. Since the mice were profoundly granulocy-
tropic in those studies, an effect of IL 1 on the neutrophils
was considered unlikely. Also, the beneficial effects of IL 1 on
hematopoiesis [17] were not demonstrated in our short-term
experiments [1, 2]. In the IL 1 studies, no effect of IL 1 on
macrophages could be demonstrated [1]. The most convincing
argument against an effect on microbial function of mac-
rophages, however, came from the microbial clearance data,
which failed to demonstrate a difference between IL 1-treated
and control mice [1, 2, 15]. In the present study, we have
obtained similar results with IL 6, i.e., the numbers of bacteria
in the blood and the various organs were similar in IL 1-treated
mice and control mice.

It is assumed that cytokines like TNF and IL 1 contribute to
death from infection [18–20]. It could well be that early treat-
ment with IL 1, and to a much lesser extent with IL 6, reduces
the lethal effects of these cytokines. This protection could be
produced by down-regulation of receptors for these cytokines
in the lethal phase. The down-regulation of TNF receptors by
IL 1 treatment, which has recently been described to occur in vitro,
is in agreement with this concept [21].

In conclusion, whatever the mechanisms of IL 1-induced pro-
tection against death due to lethal infection may be, IL 6 does
not appear to be a critical intermediate cytokine.

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