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

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

1 Introduction

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

IL 6 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 IL 1 is a potent inducer of IL 6, the latter could be responsible for the enhanced survival of animals treated with IL 1, e.g., by inducing a hepatic acute-phase protein. Therefore, we have compared the effects of IL 6 and IL 1 on survival of lethally infected mice. In addition, we have investigated the kinetics of injected IL 6 and IL 1, 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 IL 1α (rIL 1α), which was kindly provided by Dr. Peter Lomedico, Hoffmann-La Roche, Nutley, NJ, was used in the majority of the experiments. rIL 1β (kindly provided by Dr. Alan Shaw, Biogen/Glaxo, Geneva, Switzerland) was also used. These IL 1 preparations contained <30 pg lipopolysaccharide (LPS) per mg of protein. Human rIL 6, containing <3 pg LPS/µg of protein was produced as published elsewhere [8].

IL 1 and IL 6 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 IL 1 (100°C for 20 min).

2.3 Infection model

Mice were rendered granulocytopenic (<0.5 × 10⁹ 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 × 10⁷ 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 IL 1, IL 6 or heat-inactivated IL 1, 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 1:10⁶ 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.

![Figure 1](image1.png)

**Figure 1.** The effect of IL1α and of IL6 treatment on the survival of granulocytic 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](image2.png)

**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 in survival between the groups is significant at $p < 0.025$. Each group consisted of 22 mice.
4 Discussion

In the present study, we have investigated the hypothesis that IL6 is the central mediator of IL1-induced protection against lethal bacterial infection in mice. The experiments show that IL6 is 10–100 times less potent than IL1 in protecting mice. If IL1 induced a large amount of IL6 in vivo, these results still would not rule out an IL6-mediated pathway. Although we could indeed demonstrate that IL1 is a potent inducer of IL6 in mice, the serum concentrations of IL6 after an i.p. injection of 80 ng IL1 are quite similar to those after an injection of the (barely protective) 80 ng dose of IL6 i.p. Taking these data together, the hypothesis mentioned above has to be refuted.

The next question we addressed was whether IL1 and IL6 would potentiate each other. Using suboptimal dosages of each cytokine, we could not detect any synergism. However, the 800-ng dose of IL6 had some protective effect, and these results are reminiscent of experiments with tumor necrosis factor (TNF), in which a similar high dose was needed to find some protection [15, 16]. Since we observed that IL6 does induce minute amounts to IL1 in vivo, the protection by IL6 might be mediated via IL1.

The actual mechanism responsible for increase in survival induced by IL1, IL6 and TNF remains unclear. In our previous studies direct antimicrobial effects of IL1 were ruled out in vitro [1, 2]. Since the mice were profoundly granulocytopenic in those studies, an effect of IL1 on the neutrophils was considered unlikely. Also, the beneficial effects of IL1 on hematopoiesis [17] were not demonstrated in our short-term experiments [1, 2]. In the IL1 studies, no effect of IL1 on macrophages could be demonstrated [1]. The most convincing argument against an effect on microbial function of macrophages, however, came from the microbial clearance data, which failed to demonstrate a difference between IL1-treated and control mice [1, 2, 15]. In the present study, we have obtained similar results with IL6, i.e., the numbers of bacteria in the blood and the various organs were similar in IL1-treated mice and control mice.

It is assumed that cytokines like TNF and IL1 contribute to death from infection [18–20]. It could well be that early treatment with IL1, and to a much lesser extent with IL6, 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 IL1 treatment, which has recently been described to occur in vitro, is in agreement with this concept [21].

In conclusion, whatever the mechanisms of IL1-induced protection against death due to lethal infection may be, IL6 does not appear to be a critical intermediate cytokine.

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5 References

Announcements

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