Endotoxin down-regulates monocyte and granulocyte interleukin-6 receptors without influencing gp130 expression in humans


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Interleukin (IL)-6 is important for host defense against various pathogens. The IL-6 receptor (IL-6R) complex consists of a ligand-binding component (IL-6R) and a signal-transducing component (gp130). In a study designed to obtain insight into the regulation of this receptor complex during inflammation, 8 healthy subjects received an intravenous injection of lipopolysaccharide (LPS; 4 ng/kg), and receptor expression was determined on blood leukocytes by use of fluorescence-activated cell cytometry. LPS induced a transient decrease in monocyte and granulocyte IL-6R expression but did not influence gp130. The plasma concentrations of soluble IL-6R and soluble gp130 did not change after LPS administration. Expression of the receptor for leukemia inhibitory factor, a member of the IL-6R family, remained unaltered after LPS injection. In whole blood in vitro, LPS and gram-positive stimuli and proinflammatory cytokines were capable of down-modulating the IL-6R. Monocytes and granulocytes may down-regulate IL-6R at their surface upon their first interaction with bacterial antigens.
uated the effect of gram-positive stimuli and proinflammatory cytokines on expression of the IL-6R complex in whole blood in vitro.

Subjects and Methods

**Human endotoxemia model.** Eight men (mean age, 23 years; range, 19–29) were admitted to the Clinical Research Unit of Academic Medical Center in Amsterdam. Each received an intravenous injection of *Escherichia coli* LPS (lot G; US Pharmacopeial Convention, Rockville, MD) over 1 min in an antecubital vein at a dose of 4 ng/kg body weight. All subjects were in good health, as documented by history, physical examination, and hematologic and biochemical screening. Blood for fluorescence-activated cell cytometry (FACS) analysis was obtained directly before LPS administration (t = 0 h) and at 1, 2, 4, 6, and 24 h thereafter. These blood samples were drawn in heparin-containing vacuum tubes and immediately put on ice. Blood for ELISA was obtained directly before LPS administration (t = 0 h) and at 0.5, 1, 1.5, 2, 3, 4, 5, 6, 8, 12, and 24 h thereafter. This blood was drawn in K2-EDTA-containing tubes and centrifuged at 2000 g for 20 min at 4°C. The plasma was stored at −20°C until the assay was done.

**Assays.** The following ELISAs (with detection limits) were used according to manufacturers’ instructions: IL-6 (Central Laboratory of the Netherlands Red Cross Blood Transfusion Service [CLB], Amsterdam; 2.2 pg/mL), soluble IL-6R (CLB; 2.04 ng/mL), soluble gp130 (R&D Systems Europe, Abingdon, UK; 20 ng/mL), and LIF (R&D Systems; 23.4 pg/mL).

**Whole blood stimulation.** Whole blood was stimulated as described elsewhere [19, 20]. Blood was collected aseptically from healthy subjects by use of a sterile collecting system consisting of a butterfly needle connected to a syringe (Becton Dickinson, Rutherford, NJ). For anticoagulation, we used sterile heparin (LEO Pharmaceutical, Weesp, The Netherlands; final concentration, 10 U/mL blood). Whole blood diluted 1 : 2 in sterile RPMI 1640 (Gibco BRL Life Technologies, Grand Island, NY) was stimulated with ice-cold isotonic NH4Cl solution (155 m

Endotoxemia in healthy subjects.** Injection of LPS induced a decrease in peripheral blood monocytes (P < .05; table 1). Granulocyte counts initially decreased and then increased after 2 h (P < .05; table 1). At baseline, IL-6R, gp130, and LIF-R were detectable at the surface of peripheral blood monocytes and granulocytes (figure 1). LPS administration was associated with a decrease in the surface expression of IL-6R on both cell types, which reached nadirs after 2–6 h (monocytes: 0 h, 115.8 ± 16.5; 2 h, 37.0 ± 8.4, P < .001; granulocytes: 0 h, 137.0 ± 22.3; 6 h, 34.3 ± 5.5, P = .001; figure 2, upper panels). In contrast, gp130 expression did not change on monocytes or granulocytes after LPS injection (figure 3, upper panels). Furthermore, for both cell types, LIF-R expression remained unchanged during endotoxemia (data not shown).

Soluble IL-6R and soluble gp130 were detectable in plasma of all 8 volunteers at baseline (398.8 ± 35.8 and 236.6 ± 22.3 ng/mL, respectively). LPS administration did not influence the concentrations of these soluble receptors (figure 2, figure 3, lower panels). At baseline, neither IL-6 nor LIF was detectable in plasma. Plasma IL-6 concentrations increased strongly after LPS injection, peaking after 3 h (5.99 ± 1.14 ng/mL, P < .05),

### Table 1. Effect of intravenous lipopolysaccharide (LPS) on numbers of circulating monocytes and granulocytes.

<table>
<thead>
<tr>
<th>Time, h</th>
<th>Monocytesa</th>
<th>Granulocytesa</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.45 ± 0.04</td>
<td>2.7 ± 0.3</td>
</tr>
<tr>
<td>1</td>
<td>0.40 ± 0.02</td>
<td>0.7 ± 0.1</td>
</tr>
<tr>
<td>2</td>
<td>0.05 ± 0.03</td>
<td>3.0 ± 0.5</td>
</tr>
<tr>
<td>4</td>
<td>0.08 ± 0.03</td>
<td>7.0 ± 0.7</td>
</tr>
<tr>
<td>6</td>
<td>0.20 ± 0.03</td>
<td>10.2 ± 0.8</td>
</tr>
<tr>
<td>24</td>
<td>0.65 ± 0.04</td>
<td>8.6 ± 0.8</td>
</tr>
</tbody>
</table>

**NOTE.** LPS (4 ng/kg) was given as intravenous injection at t = 0 h. Data are mean ± SE cells × 105/L of 8 healthy volunteers.

a P < .05 for changes in time by analysis of variance.
Figure 1. Expression of interleukin-6 receptor (IL-6R) and gp130 and binding of leukemia inhibitory factor receptor (LIF-R) to normal monocytes and granulocytes. Histograms are cell subsets of 1 subject (representative of 8 donors). Open and shaded histograms represent nonspecifically and specifically stained cells, respectively. FITC, fluorescein isothiocyanate; PE, phycoerythrin.

Figure 2. Monocyte and granulocyte interleukin-6 receptor (IL-6R) and plasma soluble IL-6R after intravenous injection of lipopolysaccharide (lot G, 4 ng/kg) into 8 healthy subjects. Cellular IL-6R expression was determined by flow cytometry (see Subjects and Methods section). Results are expressed as difference between specific mean channel fluorescence (MCF) and nonspecific MCF ( ). P values are for changes in time by 1-way analysis of variance. NS, not significant by 1-way analysis of variance.

Discussion

IL-6 acts on cells via an interaction with a functional receptor complex that is composed of the ligand-binding IL-6R and the
Monocyte and granulocyte gp130 and plasma soluble gp130 after intravenous injection of lipopolysaccharide (lot G, 4 ng/kg) into 8 healthy subjects. Cellular gp130 expression was determined by flow cytometry (see Subjects and Methods section). Results are expressed as difference between specific mean channel fluorescence (MCF) and nonspecific MCF (mean ± SE). NS, not significant by 1-way analysis of variance (vs. time).

Figure 3.

Monocyte and granulocyte gp130 and plasma soluble gp130 after intravenous injection of lipopolysaccharide (lot G, 4 ng/kg) into 8 healthy subjects. Cellular gp130 expression was determined by flow cytometry (see Subjects and Methods section). Results are expressed as difference between specific mean channel fluorescence (MCF) and nonspecific MCF (mean ± SE). NS, not significant by 1-way analysis of variance (vs. time).

Figure 4.

Lipopolysaccharide (LPS) causes time-dependent down-regulation of monocyte and granulocyte interleukin-6 receptor (IL-6R) in whole blood in vitro. Whole blood was incubated for indicated periods in presence or absence of LPS (10 ng/mL). Bars show difference between specific mean channel fluorescence (MCF) and nonspecific MCF of 4 different donors (mean ± SE).
of only the ligand-binding part of the functional IL-6R complex. In a pathophysiologic way, this finding is not unexpected, because IL-6 responsiveness of cells is determined by IL-6R expression rather than by expression of gp130 [4].

The present data extend earlier findings on the regulation of TNF receptors (TNF-Rs) in normal subjects exposed to LPS and in patients with sepsis, in whom both type I and type II TNF-Rs are down-modulated on monocytes and granulocytes [19, 20, 29, 30]. Reduced TNF-R expression on inflammatory cells upon exposure to infectious pathogens may reflect a mechanism by which the host protects itself against excessive toxicity evoked by this potent proinflammatory cytokine. A pathophysiologic explanation for reduced IL-6R expression seems less clear. Indeed, IL-6 does not cause serious toxicity, even when administered at high doses [31, 32], and a number of studies have documented anti-inflammatory effects of IL-6, including inhibition of TNF production and stimulation of release of soluble TNF and IL-1 inhibitors [33–35]. It should be noted, however, that intravenous LPS and sepsis also cause down-regulation of the type II IL-1 receptor, which serves a purely anti-inflammatory role by functioning as an IL-1 decoy receptor [20, 36]. Together, these data suggest that acute inflammation results in down-modulation of both pro- and anti-inflammatory cytokine receptors at the surface of monocytes and granulocytes.

The LPS-induced decrease in IL-6R expression was not accompanied by an increase in the plasma concentrations of soluble IL-6R. In previous studies, the down-regulation of cellular TNF-R after LPS injection was associated with enhanced release of soluble TNF-R, although a direct correlation between the 2 phenomena could not be demonstrated [19, 20, 30]. In contrast, reduced type II IL-1R expression was not accompanied by increased plasma concentrations of soluble type II IL-1R [20]. It remains to be established whether the down-modulation of IL-6R (and other cytokine receptors) during endotoxemia is the result of shedding or internalization. The unaltered plasma levels of soluble IL-6R may have been related to the relatively mild challenge or to the possibility that putative shedding of IL-6R by circulating monocytes and granulocytes does not induce significant changes in the large pool of soluble IL-6R in the circulation. In addition, this pool may be derived from cells not present in blood. Furthermore, while inflammatory diseases invariably are associated with elevated circulating levels of IL-6, such conditions can result in increased

Figure 5. Lipopolysaccharide (LPS) does not influence monocyte and granulocyte gp130 in whole blood in vitro. Whole blood was incubated for indicated times in presence or absence of LPS (10 ng/mL). Bars show difference between specific mean channel fluorescence (MCF) and nonspecific MCF of 4 different donors (mean ± SE).

Figure 6. Gram-positive stimuli and cytokines induce down-regulation of monocyte and granulocyte interleukin-6 receptor (IL-6R) in whole blood in vitro. Whole blood was incubated 4 h in presence or absence of lipoteichoic acid (LTA; 1 μg/mL), heat-killed Staphylococcus aureus (HKSA; 10^7 cfu/mL), staphylococcal enterotoxin B (SEB; 1 μg/mL), recombinant human IL-6 (10 ng/mL), recombinant human interferon (IFN)-γ (10 ng/mL), and recombinant human tumor necrosis factor (TNF; 10 ng/mL). Bars are difference between specific mean channel fluorescence (MCF) and nonspecific MCF of 4 different donors (mean ± SE).
ular mechanisms and the functional consequences of this re-

bacteria. Further studies are warranted to evaluate the molec-
or gram-positive stimuli in vitro. Thus, monocytes and gran-
does not influence gp130 expression or LIF binding. Similar
normal subjects is associated with down-regulation of IL-6R
response and has a pivotal role in host defense against various

result in detectable LIF in blood. In accordance, in baboons
administration, suggesting that the expression of functional
r complex [40]. Hence, although the IL-6R functions ex-
clusively to present IL-6 to surface-expressed gp130, the LIF-
R is critical for signal transduction itself. In addition, unlike
the IL-6R, the structure of the LIF-R is closely related to that
of gp130 [41]. In an earlier investigation, LPS injection into rats increased LIF-R mRNA levels in hepatocytes [28]. In our study, we found that the binding of recombinant LIF to cir-
culating monocytes and granulocytes did not change after LPS
administration, suggesting that the expression of functional
LIF-R/gp130 complexes remained unaltered. LPS also did not
induce LIF release into the circulation. Some, but not all, pa-
tients with sepsis have elevated LIF concentrations in the cir-
culation [42, 43], whereas LIF is undetectable in patients with
malaria [16]. Conceivably, only severe inflammatory stimuli re-
result in detectable LIF in blood. In accordance, in baboons
challenged with a lethal dose of live E. coli, LIF plasma levels
were much higher than in baboons infused with a sublethal
dose of bacteria [44].

IL-6 is an important mediator of the acute phase protein
response and has a pivotal role in host defense against various
classes of pathogens. We report here that LPS injection into
normal subjects is associated with down-regulation of IL-6R
expression on peripheral blood monocytes and granulocytes but
does not influence gp130 expression or LIF binding. Similar
changes were found upon stimulation of whole blood with LPS
or gram-positive stimuli in vitro. Thus, monocytes and gran-
ulocytes may respond with a reduction in IL-6R expression on
their surface shortly after their first interaction with invading
bacteria. Further studies are warranted to evaluate the mole-
cular mechanisms and the functional consequences of this re-
sponse during clinical infection.

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