IL-7 Restores Lymphocyte Functions in Septic Patients

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IL-7 Restores Lymphocyte Functions in Septic Patients

Fabienne Venet,* Anne-Perrine Foray,* Astrid Villars-Méchin,* Christophe Malcus,* Françoise Poitevin-Later,* Alain Lepape,‡ and Guillaume Monneret*†

Septic syndrome is the leading cause of mortality for critically ill patients worldwide. Patients develop lymphocyte dysfunctions associated with increased risk of death and nosocomial infections. In this study, we performed preclinical experiments testing the potential of recombinant human IL-7 (rhIL-7) as a lymphostimulating therapy in sepsis. Circulating IL-7 and soluble IL-7 receptor α-chain (soluble CD127) concentrations were measured in plasma, whereas cellular CD127 expression was evaluated on circulating CD4+ and CD8+ lymphocytes from septic shock patients and healthy volunteers. Lymphocyte proliferation, IFN-γ production, STAT5 phosphorylation, and B cell lymphoma 2 induction were measured ex vivo in response to T cell stimulation in the presence or not of rhIL-7. We show that IL-7 pathway (plasmatic IL-7 concentration and cellular and soluble CD127 expressions) is not overly altered and remains activable in septic patients. Most importantly ex vivo treatment of patients’ cells with rhIL-7 significantly improves lymphocyte functionality (CD4+ and CD8+ lymphocyte proliferations, IFN-γ production, STAT5 phosphorylation, and B cell lymphoma 2 induction after stimulation). To our knowledge, this constitutes the first report of rhIL-7 ability to restore normal lymphocyte functions in septic patients. These results support the rational for initiating a clinical trial testing rhIL-7 in septic shock. The Journal of Immunology, 2012, 189: 000–000.

S eptic syndrome is the leading cause of mortality for critically ill patients worldwide although an enormous effort has been expended during the past 20 y to find new therapies that decrease the mortality of this syndrome (1). It is now largely demonstrated that septic patients develop severe immune alterations (innate and adaptive), which intensity and duration are correlated with increased risk of death and nosocomial infections (1). Thus, immune-stimulating therapies are now considered in the treatment of sepsis (2).

Sepsis-induced lymphocyte alterations share many similarities with immune dysfunctions described in patients with chronic viral infections such as HIV (3–5). In particular, severe lymphopenia due to increased apoptosis, decreased T cell proliferation, and cytokine production after stimulation as well as increased percentage of CD4+CD25+ regulatory T cells (Treg) have been described in both clinical contexts. In HIV infection, innovative immunorestorative therapies such as recombinant human IL-7 (rhIL-7) are currently tested as adjunctive treatment in phase I and II clinical trials.

IL-7 is a 25-kDa glycoprotein secreted by stroma cells and other epithelial cells. IL-7 is a nonredundant cytokine for T and B cell development and function. IL-7 activity is mediated via its binding to a receptor (IL-7R) constituted of two chains: the α-chain (CD127) and the common cytokine receptor γ-chain. This receptor is expressed continuously on most resting human T cells with high levels on naive and central memory cells and lower levels on Treg (6). In healthy volunteers, rhIL-7 therapy induces B cell lymphoma 2 (BCL2) upregulation and sustained increased in peripheral blood CD4+ and CD8+ T cell numbers. Consequently, this T cell expansion caused a significant broadening of circulating TCR repertoire diversity independently of subject’s age (7). Interestingly, rhIL-7 therapy is associated with a reduction in the circulating proportion of Treg (7).

In chronic viral infection, rhIL-7 treatment has proven to be safe, well tolerated and to result in potent immunoreparative effects (4). In sepsis, three studies in mice have described beneficial effects of rhIL-7 treatment on mortality and sepsis-induced immune dysfunctions (8–10).

The objective of the current study was thus to perform an ex vivo preclinical study of rhIL-7 therapy in septic shock patients. We first tested whether parameters of IL-7 pathway were altered in patients in comparison with controls. In a second set of experiments, patients’ lymphocyte response to rhIL-7 treatment was tested ex vivo. These experiments should provide the preliminary results necessary to the initiation of a clinical trial testing rhIL-7 in septic shock.

Materials and Methods

Patients

Septic patients belong to a global study on intensive care unit (ICU)-induced immune dysfunctions approved by our Institutional Review Board for ethics (“Comité de Protection des Personnes”) and registered at Ministère Français de la Recherche et de l’Enseignement (no. DC-2008-509). The study group consisted in 70 septic shock patients according to the diagnostic criteria of the American College of Chest Physician/Society of Critical Care Medicine (Table I) (11). The onset of septic shock was defined as the beginning of vasopressor therapy. EDTA-anticoagulated blood was collected at two time points after diagnosis: day 1–2 and day 3–4. Mortality was defined as death occurring within 28 d after the onset of
rhIL-7 RESTORES SEPSIS-INDUCED LYMPHOCYTE FUNCTIONS

The page contains a section discussing the restoration of lymphocyte functions in sepsis, mentioning the use of rhIL-7. It also includes a section on reagents used, quantification of plasma CD127 and IL-7 concentrations, cell isolation and culture, tritiated thymidine incorporation, flow cytometry, and statistics. The section on statistics includes a discussion on p values and statistical significance.

Results
Plasmonic IL-7 concentration is slightly increased after septic shock

Plasmonic IL-7 concentration was measured in septic shock patients at days 1–2 and 3–4 (n = 24) in comparison with healthy controls (n = 26). We observed that circulating IL-7 level was increased in septic shock patients at day 1–2 and at day 3–4 in comparison with controls (Fig. 1A). However, these levels remained relatively low (<10 pg/ml) and no significant differences were observed between survivors (n = 15) and nonsurvivors (n = 9; Fig. 1B) or between patients developing or not a nosocomial episode (n = 4 and n = 20, respectively; Fig. 1C).

This suggests that IL-7 plasmonic level may be increased in a homeostatic manner after septic shock. Because circulating IL-7 concentration is mostly regulated by its scavenging rate by T cells, such increased concentration is not surprising in markedly lymphopenic hosts such as septic shock patients (Table I) (4, 15).

CD127 expression is maintained on CD4+ and CD8+ lymphocytes after septic shock

A strong regulation of IL-7 receptor α-chain (CD127) has been described in various clinical conditions including HIV infection (16). We thus measured CD127 expression by flow cytometry on CD4+ and CD8+ T cells from 20 septic shock patients sampled at days 1–2 and 3–4 after the onset of shock in comparison with 30 healthy volunteers (Fig. 2). No significant differences were observed between patients and controls at day 1–2 either on CD4+ cells (Fig. 2A) or on CD8+ cells (Fig. 2B). At day 3–4, a slightly decreased CD127 expression was measured on CD8+ T cells from septic patients in comparison with healthy volunteers (Fig. 2B), but no difference was observed for CD4+ cells (Fig. 2A). In paired samples, a decrease over time was observed for CD127 expression on CD4+ between days 1–2 and 3–4 but not on CD8+ cells. To note, absolute numbers of circulating CD4+CD127+ and CD8+CD127+ cells were calculated. As expected considering the marked lymphopenia observed after septic shock, these parameters were significantly decreased in septic patients versus healthy volunteers (data not shown).

No significant differences were observed between survivors (n = 12) and nonsurvivors (n = 8) for CD127 expression measured either on CD4+ cells (Fig. 2C) or on CD8+ lymphocytes (Fig. 2D). Similarly, no significant differences were observed between patients who will develop or not a nosocomial episode (n = 4 and n = 16, respectively; Fig. 2E, 2F). Overall, these results show that CD127 expression is not overtly regulated on circulating lymphocytes after septic shock.

The plasmatic concentration of the soluble form of CD127 is increased in patients with ICU-acquired nosocomial infection after septic shock

Importantly, plasmatic concentration of sCD127, known to possess in vitro antagonistic activity on IL-7 (12, 16) was measured in septic shock patients (n = 33) and healthy volunteers (n = 16). No significant differences were observed between patients and healthy controls neither at day 1–2 nor at day 3–4. This is in contrast with the observation made in HIV infection of a significantly increased sCD127 plasmatic level (12, 16). Meanwhile, a
significant decrease was measured between these two time points in patients (Fig. 3A).

No differences were observed between survivors (n = 20) and nonsurvivors (n = 13), although a significant decrease over time was observed in both groups of patients (Fig. 3B). Interestingly and despite the low number of patients in each group, a significantly higher concentration was measured in patients who developed a nosocomial episode (n = 5) in comparison with patients who remained free of any secondary infectious challenge (n = 28). This difference was present both at day 1–2 and at day 3–4 (Fig. 3C).

In total, this first set of observational studies shows that, in contrast with results observed during chronic viral infections, parameters of the IL-7 pathway are not markedly modified after septic shock. This suggests that this pathway remains potentially activable during sepsis and thus that rhIL-7 could restore normal lymphocyte functions in patients. To test this hypothesis, we de-

![Figure 1](image-url)

**Figure 1.** Plasmatic IL-7 concentration in septic shock patients. Plasmatic IL-7 concentration was measured in septic patients (n = 24) at day 1–2 (D1–2) and day 3–4 (D3–4) after the onset of shock in comparison with healthy volunteers (HV, n = 26) (A), in survivors (S, n = 15) versus nonsurvivors (NS, n = 9) (B), and in patients who will develop a secondary infection (NI, n = 4) versus patients remaining free of any nosocomial episode (NoNI, n = 20) (C). Nonparametric Mann–Whitney U test was used to compare results between groups.

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**Table I. Demographic, clinical, and immunological data for septic shock patients**

<table>
<thead>
<tr>
<th>Clinical data</th>
<th>Male</th>
<th>73 [62–80]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at admission (y)</td>
<td>44 (63)</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAPS II at diagnosis of shock</td>
<td>58 [47–67]</td>
<td></td>
</tr>
<tr>
<td>SOFA score</td>
<td>11 [8–13]</td>
<td></td>
</tr>
<tr>
<td>Comorbidities</td>
<td>0</td>
<td>23 (33)</td>
</tr>
<tr>
<td>≥1</td>
<td>47 (67)</td>
<td></td>
</tr>
<tr>
<td>Initial infection</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bacilli Gram−</td>
<td>19 (27)</td>
<td></td>
</tr>
<tr>
<td>Cocci Gram+</td>
<td>19 (27)</td>
<td></td>
</tr>
<tr>
<td>Fungi</td>
<td>5 (7)</td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td>11 (16)</td>
<td></td>
</tr>
<tr>
<td>Type of infection</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Community-acquired</td>
<td>43 (61)</td>
<td></td>
</tr>
<tr>
<td>Hospital-acquired</td>
<td>27 (39)</td>
<td></td>
</tr>
<tr>
<td>Site of infection</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulmonary</td>
<td>24 (34)</td>
<td></td>
</tr>
<tr>
<td>Abdominal</td>
<td>17 (24)</td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td>29 (41)</td>
<td></td>
</tr>
<tr>
<td>Mortality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonsurvivors</td>
<td>24 (34)</td>
<td></td>
</tr>
<tr>
<td>Secondary infections</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Occurrence</td>
<td>14 (20)</td>
<td></td>
</tr>
</tbody>
</table>

**Immunological data**

| CD3<sup>+</sup>CD4<sup>+</sup> T lymphocytes | D3–4 | 355 [190–530] |
| Treg (%)                                 | D3–4 | 10 [8–14]    |
| mHLA-DR (%)                              | D3–4 | 41 [19–70]   |

Blood samples were obtained from 70 septic shock patients after the onset of shock. For clinical parameters, categorical data are presented as number of cases and percentages respective to the total population in parentheses. Continuous data as well as biological parameters are presented as medians and interquartile ranges [Q1–Q3] in brackets. The following leukocyte subsets were analyzed at day 3–4 after the onset of shock: number of circulating CD3<sup>+</sup>CD4<sup>+</sup> T lymphocytes per microliter, percentage of CD4<sup>+</sup>CD25<sup>Bright</sup>CD127<sup>Low</sup> Treg measured among CD3<sup>+</sup>CD4<sup>+</sup> T lymphocytes and percentage of monocytes expressing HLA-DR among total monocytes (mHLA-DR). Normal values from our laboratory for age-matched individuals are 500–1250 CD4<sup>+</sup> T cells/µl, 5–7% Treg, and >90% mHLA-DR.

SAPS II, Simplified Acute Physiologic Score II calculated at inclusion in the protocol; SOFA score, Sequential Organ Failure Assessment score measured after 24 h of ICU stay.
veloped ex vivo functional assays with purified mononuclear cells from septic shock patients incubated with rhIL-7.

**rhIL-7 restores ex vivo sepsis-induced decreased cell proliferation**

Lymphocyte proliferation was measured after TCR stimulation of PBMCs extracted from septic shock patients \((n = 10)\) and healthy volunteers \((n = 10)\) and cultured in presence or not of rhIL-7. Proliferation was evaluated by tritiated thymidine incorporation.

Septic patients presented with a significantly decreased proliferation in response to TCR stimulation in comparison with healthy volunteers (Fig. 4A). Importantly, cell incubation with rhIL-7 significantly increased this proliferative response in patients whereas no significant effect was measured in healthy volunteers (Fig. 4A). This is illustrated by the significant difference of rhIL-7–induced fold increase in cell proliferation observed between patients and healthy controls (Fig. 4B).

**rhIL-7 restores ex vivo sepsis-induced decreased CD4+ and CD8+ T cell proliferations**

To decipher whether this rhIL-7–induced cell proliferation was affecting selectively CD4+ and/or CD8+ cells, PBMCs extracted from septic patients \((n = 7)\) and healthy volunteers \((n = 4)\) were stained with CFSE before culture in presence of TCR stimulation and rhIL-7.

We observed that both CD4+ (Fig. 5A, 5C) and CD8+ (Fig. 5B) T cell proliferations were decreased in patients versus controls. This decrease was significant for CD4+ T lymphocytes (Fig. 5A). Most importantly, incubation with rhIL-7 significantly increased CD4+ lymphocyte proliferation to a level that was not different from that of healthy volunteers (Fig. 5A). A similar trend was observed for CD8+ T cells (Fig. 5B). Interestingly, the number of CD4+ cell divisions after rhIL-7 stimulation was increased in septic shock patients to a level similar to control values (Fig. 5D). Similar results were observed for CD8+ cells (data not shown). Representative examples of CFSE stainings of CD4+ T cells from one septic shock patient and one healthy control are shown in Fig. 5C. These results suggest that rhIL-7 is efficacious in restoring both CD4+ and CD8+ T cell dysfunctions after septic shock.

**rhIL-7 restores ex vivo sepsis-induced decreased IFN-γ lymphocyte production**

Another aspect of sepsis-induced lymphocyte dysfunctions is a reduction in IFN-γ production by lymphocytes. We thus measured by flow cytometry intracellular IFN-γ production by CD8+ T cells.
in patients \( n = 12 \) and controls \( n = 10 \) after TCR stimulation and incubation with rhIL-7.

We observed that TCR-induced IFN-\( \gamma \) production was significantly reduced in patients versus controls (Fig. 6). Most importantly, incubation of patients’ cells with rhIL-7 significantly increased this cytokine response to a level that was not different from healthy controls. Representative examples of flow cytometry stainings are shown in Fig. 6B. These results show that rhIL-7 is efficacious in restoring CD8\(^{+}\) T cell dysfunctions after septic shock.

**rhIL-7 efficiently activates parameters of its intracellular pathway in septic shock patients**

A key signaling molecule for IL-7 is STAT5 (signal transducer and activator of transcription 5), which is phosphorylated following recruitment of CD127. Beside, one significant consequence of CD127 signaling is the maintenance of cell survival by increasing BCL2 protein expression. We thus investigated the expressions of these molecules in response to TCR stimulation and/or rhIL-7 in septic patients \( n = 10 \) and controls \( n = 10 \).

To our knowledge, we show for the first time that TCR stimulation was associated with a significantly decreased induction of STAT5 phosphorylation (Fig. 7A, 7B) and BCL2 expression (Fig. 7C) in patients compared with healthy volunteers. Most importantly, cell incubation with rhIL-7 was able, by itself and after TCR stimulation, to significantly increase the expression of these molecules in patients and controls (Fig. 7). This shows that IL-7 intracellular pathway is mobilizable in septic patients although its activation is not adequate after TCR stimulation alone.

**FIGURE 3.** Plasmatic concentration of soluble IL-7R \( \alpha \)-chain in septic shock patients. Plasmatic concentration of the soluble fraction of IL-7R \( \alpha \)-chain \( (sCD127) \) was measured in septic patients \( n = 33 \) at day 1–2 (D1–2) and day 3–4 (D3–4) after the onset of shock versus healthy volunteers \( (HV, n = 16) \) \( (A) \), in survivors \( (S, n = 20) \) versus nonsurvivors \( (NS, n = 13) \) \( (B) \), and in patients who will develop a secondary infection \( (NI, n = 5) \) versus patients remaining free of any nosocomial episode \( (NoNI, n = 28) \) \( (C) \). Nonparametric Mann–Whitney \( U \) test was used to compare results between groups. Nonparametric Wilcoxon paired test was used to evaluate evolution over time within a group.

**FIGURE 4.** Lymphocyte proliferation is restored by rhIL-7 in septic shock patients. Mononuclear cells were isolated from peripheral blood of septic shock patients (gray columns, \( n = 10 \)) and healthy volunteers (open columns, \( n = 10 \)). Cells were cultured for 5 d in the presence or not of anti-CD2/CD3/CD28 Ab-coated beads (TCR Stim, ratio of beads/cells = 4:1) and rhIL-7 (100 ng/ml). Cell proliferation was evaluated by \([^{3}H]\)thymidine incorporation. \( (A) \) Results are presented as mean \( \pm \) SEM of proliferative response evaluated for each cell culture condition and each experiment as the ratio versus non-stimulated cells response. \( (B) \) Results are presented as individual values of rhIL-7–induced proliferation evaluated for each experiment as the ratio of the proliferative response induced by TCR stimulation alone or in the presence of rhIL-7. Nonparametric Mann–Whitney \( U \) test was used to compare results between groups. Nonparametric Wilcoxon paired test was used to evaluate evolution over time within a group.
Discussion

Severe sepsis and septic shock represent the first cause of mortality in ICU (17). Septic syndromes induce alterations of the immune response that have, for long, been solely considered as an overwhelming proinflammatory syndrome. However, the failure of numerous clinical trials testing anti-inflammatory drugs to show any improvement in mortality has led to the re-evaluation of our understanding of severe sepsis and septic shock pathophysiology. In line, it is now globally accepted that, in parallel with a tremendous proinflammatory response leading to shock and organ dysfunctions, septic patients develop an immnosuppressive phase associated with immune dysfunctions (2, 3). Importantly, it has recently been shown that, in patients, these dysfunctions are not only observed at the systemic level but also locally in organs therefore illustrating the importance of this compensatory mechanism (18). In addition, observational clinical studies have linked the intensity and duration of these sepsis-induced immune dysfunctions with increased risk of death and of secondary nosocomial infections (3). Consequently, clinical trials testing immunostimulating drugs are now initiated in septic patients (2).

Sepsis-induced immune alterations affect both innate and adaptive immune responses (3, 19). So far, most work has been devoted to the study of the innate part of these sepsis-induced immune dysfunctions. Conversely, far less work has been dedicated to the study of lymphocyte alterations although a link between a reduced delayed-type hypersensitivity response (predominantly mediated by T cells and a hallmark of immune suppression) in ICU patients and increased risk of nosocomial infections and death has been described more than 30 y ago (20). Indeed, sepsis-induced lymphocyte dysfunctions make up 1) a dramatic lymphopenia affecting every lymphocyte subsets associated with major apoptosis, 2) functional alterations such as decreased proliferation and cytokine production in response to stimulation, 3) phenotypic alterations such as increased coinhibitory receptor (CTLA-4 and pro-
grammed cell death-1 [PD-1]) and decreased costimulatory receptor (CD80 and CD86) and CD3 expressions, 4) decreased TCR diversity, and 5) increased percentage of circulating CD4+CD25+ Treg (3, 21). These lymphocyte dysfunctions are likely illustrated in patients by viral reactivations normally solely occurring in immunocompromised hosts (CMV and herpes simplex virus). Importantly, they are associated with deleterious outcome after septic shock (22, 23). Therefore immunostimulating therapies able to restore these lymphocyte dysfunctions would represent an innovative therapeutic strategy in septic shock.

Interestingly, sepsis-induced lymphocyte dysfunctions share many similarities with cell alterations observed in patients with chronic viral infections. In particular, HIV-infected patients also present with a marked decrease in circulating CD4+ T cell number, functional alterations such as decreased lymphocyte proliferation after stimulation, phenotypic alterations such as increased coinhibitory receptor expression (i.e., PD-1), decreased TCR diversity and increased percentage of circulating CD4+CD25+ Treg (3, 21). These lymphocyte dysfunctions are likely illustrated in patients by viral reactivations normally solely occurring in immunocompromised hosts (CMV and herpes simplex virus). Importantly, they are associated with deleterious outcome after septic shock (22, 23). Therefore immunostimulating therapies able to restore these lymphocyte dysfunctions would represent an innovative therapeutic strategy in septic shock.

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We observed that parameters of the IL-7 pathway (plasmatic IL-7 concentration, CD127 expression on circulating lymphocytes and sCD127 level) were not markedly modified after septic shock. The only significant change was an increase in circulating IL-7 level in patients versus healthy controls. However, because an inverse relationship between serum IL-7 levels and lymphocyte counts has been constantly described in various settings of lymphocyte depletion (e.g., in HIV-infected patients), such increase in circulating IL-7 is not surprising in markedly lymphopenic hosts as septic shock patients. Moreover, this elevation is not of major importance since max concentrations measured in patients peaked at 13 pg/ml, whereas normal values for circulating human IL-7 range from 2 to 8 pg/ml (6).

Interestingly, cell surface and plasmatic concentrations of CD127 were not significantly different in septic patients versus

![FIGURE 6.](http://www.jimmunol.org/) IFN-γ production by CD8+ T lymphocytes is restored by rhIL-7 in septic shock patients. Mononuclear cells were isolated from peripheral blood of septic shock patients (gray columns, n = 12) and healthy volunteers (open columns, n = 10). Cells were cultured for 4 h in the presence or not of anti-CD2/CD3/CD28 Ab-coated beads (TCR Stim, ratio of beads/cells = 4:1) and rhIL-7 (100 ng/ml). IFN-γ production by CD8+ T cells was then measured by flow cytometry (intracellular staining). (A) Results are presented as mean ± SEM of percentages of IFN-γ–producing cells among total CD8+ T lymphocyte–proliferating cells. (B) One representative example of an IFN-γ staining after culture in one septic shock patient and one healthy volunteer is presented. Nonparametric Wilcoxon paired test was used to evaluate evolution over time within a group.
healthy controls. This is in contrast with results observed in HIV infection, as significantly decreased CD127 lymphocyte expression as well as marked increased concentration of its soluble form have been observed in patients (12, 16). Interestingly and despite these alterations, rhIL-7 is effective in restoring lymphocyte dysfunctions in HIV-infected patients (4). Thus, as we did not observe such alterations of IL-7 pathway in our cohort, we postulated that rhIL-7 should be all the more effective in restoring normal lymphocyte functions after septic shock.

To test this hypothesis, we measured ex vivo the response of septic patients’ lymphocytes to stimulation in the presence or absence of rhIL-7. As previously described, we observed that patients present with significantly decreased lymphocyte proliferation (both of CD4+ and CD8+ T cells) in response to TCR stimulation. In addition, IFN-γ response was decreased in these patients as well. Importantly, we describe here two additional sepsis-induced lymphocyte dysfunctions. To our knowledge, these results are the first to show that septic patients’ cells remain responsive to rhIL-7 treatment and that rhIL-7 is efficacious ex vivo in restoring sepsis-induced lymphocyte dysfunctions. Although performed ex vivo, they suggest that rhIL-7 could represent an innovative therapy in sepsis.

These data are very complimentary to results obtained in murine models of sepsis (8–10). Indeed, in mice, in vivo treatment with rhIL-7 was associated with significant improvement in T cell viability, trafficking and functionality after bacterial as well as fungal sepsis (8, 10). Importantly, in these experiments, survival was significantly improved as well. Interestingly and as observed in the current study, rhIL-7 treatment was associated with restoration of IFN-γ production and increased BCL2 expression. More generally, these animal studies showed that, although targeting adaptive immune cells, rhIL-7 therapy could impact every aspect of the immune response, including innate immune cells such as neutrophils (9). Although not tested in our study, this suggests that rhIL-7 therapy could efficiently restore both innate and adaptive immune dysfunctions after sepsis.

Moreover, results observed in ongoing clinical trials in other pathologies sharing similar immune dysfunctions further support the potential beneficial effect of rhIL-7 in sepsis. In particular, beside the improvement of T cell viability and functionality, this molecule has been shown to improve TCR repertoire diversifica-

FIGURE 7. STAT5 phosphorylation and BCL2 induction in T lymphocytes are restored by rhIL-7 in septic shock patients. Mononuclear cells were isolated from peripheral blood of septic shock patients (gray columns, n = 10) and healthy volunteers (open columns, n = 10). (A) Cells were cultured overnight in the presence or not of anti-CD2/CD3/CD28 Ab-coated beads (TCR Stim, ratio of beads/cells = 4:1) and 15 min in the presence or not of rhIL-7 (100 ng/ml). STAT5 phosphorylation in T cells was then measured by flow cytometry (pSTAT5, intracellular staining). For each experiment and culture condition, means of fluorescence intensity of pSTAT5 were normalized by value measured in the control well. (B) One representative example of a pSTAT5 staining after culture in one septic shock patient and one healthy volunteer is presented. (C) Cells were cultured 48 h in the presence or not of anti-CD2/CD3/CD28 Ab-coated beads (TCR Stim, ratio of beads/cells = 4:1) and rhIL-7 (100ng/ml). BCL2 expression in T cells was then measured by flow cytometry (intracellular staining). For each experiment and culture condition, means of fluorescence intensity of BCL2 were normalized by value measured in the control well. Results are presented as mean ± SEM. Nonparametric Wilcoxon paired test was used to evaluate evolution over time within a group.
tion, whereas septic patients present with a marked decrease in TCR repertoire diversity (21). Similarly, the effect of rhIL-7 involves the downregulation of expression of immunoregulatory receptors such as PD-1, whereas PD-1 expression has been shown to be increased on circulating cells from septic patients (24). Importantly, PD-1 knockout mice have been shown to be more resistant to sepsis than wild-type animals (24). Finally, rhIL-7 therapy also leads to a relative decrease in the frequency of Treg while an increased percentage of circulating Treg has been repeatedly shown in septic patients (25).

In total, our results strongly support the hypothesis that rhIL-7 could represent an innovative therapy in the treatment of sepsis as we show that IL-7 pathway is not significantly altered and is still functional in septic shock patients and that rhIL-7 treatment significantly restores sepsis-induced lymphocyte functions to a normal response. This supports the rational for the initiation of a clinical trial testing rhIL-7 in septic shock patients, although the adequate design of such study still deserves to be precisely determined.

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Disclosures
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