IN VITRO REACTIVATION OF HUMAN IMMUNODEFICIENCY VIRUS-1 UPON STIMULATION WITH SCRUB TYPHUS RICKETTSIAL INFECTION

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Abstract. While a number of microbial infections induce a transient burst in viral load in individuals infected with human immunodeficiency virus-1 (HIV-1), a recent study has suggested that scrub typhus may suppress HIV-1 infection. We investigated the effects of Orientia tsutsugamushi on HIV-1 infection. In vitro HIV-1 infection experiments were conducted using peripheral blood mononuclear cells (PBMC) acutely infected with R5 and X4 HIV-1 or PBMC derived from patients receiving highly active antiretroviral therapy (HAART) whose plasma viral load was undetectable. Stimulation of PBMC with O. tsutsugamushi induced production of proinflammatory cytokines and β-chemokines, and markedly down-regulated expression of CCR5. Although pretreatment with O. tsutsugamushi rendered PBMC resistant to R5 HIV-1, it otherwise enhanced HIV-1 replication. Stimulation by O. tsutsugamushi induced HIV-1 replication in PBMC from patients receiving HAART. These findings suggest that scrub typhus does not necessarily suppress HIV-1 infection and does have potential to enhance HIV-1 replication.

INTRODUCTION

Immune activation or perturbation of cytokine networks following microbial infections generally increases human immunodeficiency virus-1 (HIV-1) viremia. However, Watt and others have recently reported the possible HIV-1-inhibitory effects of scrub typhus,1 which is an acute febrile disease that is endemic in tropical Asia where HIV-1 infection is also prevalent. Their hypothesis is intriguing but also remains somehow speculative, partly because of difficulty in conducting a prospective and well-controlled clinical study in Thailand, as well as a lack of precise laboratory data supporting their hypothesis. We investigated effects of Orientia tsutsugamushi infection on in vitro HIV-1 infection of peripheral blood mononuclear cells (PBMC).

MATERIALS AND METHODS

Cells. The PBMC were isolated from healthy volunteers who were not infected with HIV, as described previously.2 Resting CD4+ T cells were isolated from HIV-1-infected individuals whose plasma viral RNA was undetectable upon receiving highly active antiretroviral therapy (HAART), as described previously.3,4

Viruses and rickettsiae. Virus stocks were prepared by transfecting 293 cells with the following HIV-1 infectious molecular clones:2 AD8 (subtype B, R5), YU-2 (subtype B, R5), NL4-3 (subtype B, X4), ELI1 (subtype B, X4), 89.6 (subtype B, R5X4), and 93JP.NH1 (subtype E, R5X4). The proinflammatory cytokines tumor necrosis factor-α (TNF-α) and interleukin-1β (IL-1β), as well as the β-chemokines regulated upon activation normal T cell expressed and secreted (RANTES) protein and macrophage inflammatory protein-1β, were not detected in these virus stocks.

Cell-free stocks of O. tsutsugamushi strains Karp or Kuroki were propagated in L929 cells.5 In certain experiments, O. tsutsugamushi stocks were pretreated at 56°C for 60 minutes. Rickettsial replication was not detected by the L929 cell culture method.

Infections. For acute infection experiments, PBMC derived from healthy volunteers were mock-infected or infected with cell-free stocks of O. tsutsugamushi strains Karp or Kuroki, and then infected with HIV-1 stocks. Inocula were standardized by reverse transcriptase (RT) activity (10,000 cpm per 4 × 10^6 cells, as determined by RT assays). Viral replication was monitored by RT activity in cell-free culture supernatants.2 For reactivation experiments, PBMC derived from patients receiving HAART were mock-infected or infected with the Karp strain, and viral replication was monitored by measuring p24 antigen levels in cell-free culture supernatants.3,4

Single-round viral replication assays. A replication-incompetent luciferase-reporter recombinant virus NL4-3 luciferase (NL4-3luc) was pseudotyped with envelope (env) protein from R5 HIV-1 JRFL or X4 HIV-1 HXB2.2 The PBMC were not treated, pretreated, or post-treated with the Karp strain (live or heat-inactivated) or supernatants from O. tsutsugamushi (Karp strain)-infected autologous PBMC, and luciferase activity in the infected cell lysates was determined.2

Flow cytometry. Cell surface expression of CCR5 and CXCR4 was determined by staining cells with phycoerythrin-conjugated anti-CCR5 monoclonal antibody 2D7 and anti-CXCR4 monoclonal antibody 12G5 (R&D Systems, Minneapolis, MN) and analyzed by FACSscan (Becton-Dickinson Immunocytochemistry Systems; San Jose, CA).

Transient expression assays. Forty million PBMC were transfected with 40 μg of pGL-HIV-1-LTR [a luciferase reporter under the control of the HIV-1 long terminal repeat (LTR)] along with 10 μg of pSV2-CAT or pSV2-Tat (encoding HIV-1 Tat), and luciferase activity in the transfected cells was determined, as described previously.2

Enzyme-linked immunosorbent assay (ELISA). Levels of cytokines were determined by commercially available ELISA kits, according to the manufacturer’s instruction (R&D Systems).

RESULTS

Dichotomous effects of O. tsutsugamushi on in vitro HIV-1 infection. In acute HIV-1 infection experiments, PBMC were infected with O. tsutsugamushi, and then infected with R5 HIV-1 (which uses chemokine receptor CCR5 to infect the cell), X4 HIV-1 (which uses CXCR4), or R5X4 HIV-1 (which uses both CCR5 and CXCR4). Stimulation with O. tsutsugamushi consistently enhanced infection with X4 or R5X4 HIV-1, irrespective of subtypes B or E (Figure
However, the R5 HIV-1-inhibitory effect of O. tsutsugamushi was not consistent; it either suppressed (Figure 1E and F and donors 1, 3, and 5 in Table 1) or enhanced (donors 2 and 4 in Table 1) replication of R5 HIV-1. Peripheral blood mononuclear cells were uninfected (squares) or infected (circles) with the O. tsutsugamushi Karp strain for 24 hours prior to HIV-1 infection, and HIV-1 replication was monitored by reverse transcriptase (RT) assays. Similar results were obtained using the Kuroki strain of O. tsutsugamushi.

To more precisely delineate how O. tsutsugamushi can modulate HIV-1 infection, we performed single-round viral replication assays in which PBMC were uninfected or infected with O. tsutsugamushi prior to or after HIV-1 infection. In these assays, pretreatment with O. tsutsugamushi suppressed R5, but not X4 HIV-1 infection (Figure 2). In contrast, post-treatment enhanced HIV-1 infection, irrespective of coreceptor usage (Figure 2). Heat-inactivated O. tsutsugamushi had effects similar to those of live O. tsutsugamushi stocks (Figure 2). Thus, O. tsutsugamushi appeared to inhibit CCR5-mediated cellular entry of R5 HIV-1 and facilitate the post-entry viral replicative cycle. In addition, the productive replication of O. tsutsugamushi is not necessary for its effects.

**Down-regulation of CCR5 expression by O. tsutsugamushi.** Since the level of CCR5 expression correlates well with infectability of cells with R5 HIV-1, we hypothesized that O. tsutsugamushi infection leads to down-regulation of CCR5 expression. Flow cytometry studies have clearly proven our hypothesis: O. tsutsugamushi infection down-regulated CCR5 expression (Figure 3 and Table 1) but had little effect on CXCR4 expression.

**Up-regulation of HIV-1 LTR activity by O. tsutsugamushi.** Next, we investigated how O. tsutsugamushi infection en-

**TABLE 1**

<table>
<thead>
<tr>
<th>Donor</th>
<th>CCR5 expression (%)</th>
<th>R5 HIV-1 infectability (cpm/µL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unstimulated</td>
<td>Stimulated</td>
</tr>
<tr>
<td>1</td>
<td>5.1</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>2</td>
<td>6.8</td>
<td>1.1</td>
</tr>
<tr>
<td>3</td>
<td>2.4</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>4</td>
<td>0.8</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>5</td>
<td>3.6</td>
<td>&lt;0.5</td>
</tr>
</tbody>
</table>

*Cell surface CCR5 expression was determined by flow cytometry 24 hours after stimulation of PBMC from five donors with the O. tsutsugamushi Karp strain. Peak reverse transcriptase titers in infection of unstimulated or stimulated PBMC with HIV-1 ADs are shown as R5 HIV-1 infectability. Results in donor 1 are also shown in Figures 1E and 3.*
hanced post-entry HIV-1 replication. In transient expression assays using PBMC, HIV-1 LTR promoter activity from pGL-HIV-1-LTR was markedly enhanced by stimulation with O. tsutsugamushi Karp strain (live or heat-inactivated), and luciferase activity in the infected cell lysates was determined. Fold induction indicates luciferase activity relative to that of a control (unstimulated) experiment. Results (mean ± SD) of triplicate experiments are shown.

Mediation of the effects of O. tsutsugamushi infection on HIV-1 infection through soluble activity. In good agreement with previous studies demonstrating that O. tsutsugamushi Karp strain (live or heat-inactivated), and luciferase activity in the infected cell lysates was determined. Fold induction indicates luciferase activity relative to that of a control (unstimulated) experiment. Results (mean ± SD) of triplicate experiments are shown.

In vitro reactivation of HIV-1 upon stimulation with O. tsutsugamushi. Finally, we tested whether stimulation with O. tsutsugamushi can induce HIV-1 replication from PBMC derived from HIV-1-infected individuals whose plasma viral RNA was undetectable after HAART. Apheresis to obtain PBMC was performed according to protocol approved by the National Institute of Allergy and Infectious Diseases Institutional Review Board (Bethesda, MD). The CD8+ T cells and HLA-DR+ cells were depleted by Dynabeads (Dynal, Lake Success, NY) CD8 and HLA-DR, and there were less than 0.1% HLA-DR+CD4+ T cells (activated CD4+ T cells) in the remaining PBMC preparations. These cells did not release HIV-1 p24 antigen without any stimulation; however, stimulation with phytohemagglutinin plus IL-2 induced in vitro HIV-1 replication in all patients tested (Table 2). When these cells were stimulated with O. tsutsugamushi, HIV-1 replication was induced in two of the four patients tested (Table 2). Thus, O. tsutsugamushi stimulation appears to have capability of inducing HIV-1 replication in patients whose plasma viremia is undetectable.

FIGURE 2. Differential effects of Orientia tsutsugamushi (OT) on R5 human immunodeficiency virus-1 (HIV-1) infection before and after cellular entry. Pretreatment with O. tsutsugamushi suppressed R5 HIV-1 infection, while post-treatment enhanced HIV-1 infection. A replication-incompetent luciferase-reporter recombinant virus pseudotyped with envelope (env) protein from R5 HIV-1 JRFL or X4 HIV-1 HXB2 was infected into peripheral blood mononuclear cells (PBMC). The PBMC were not treated, pretreated (pre), or post-treated (post) with the O. tsutsugamushi Karp strain (live or heat-inactivated), and luciferase activity in the infected cell lysates was determined. Fold induction indicates luciferase activity relative to that of a control (unstimulated) experiment. Results (mean ± SD) of triplicate experiments are shown.

DISCUSSION

Orientia tsutsugamushi is a gram-negative bacillus that is an obligate intracellular parasite, and is distributed in many Asian countries and Pacific islands. Since HIV-1 infection is

FIGURE 3. Down-regulation of expression of CCR5 by infection with Orientia tsutsugamushi. Peripheral blood mononuclear cells were infected with the Karp strain, and 24 hours later cell-surface expression of CCR5 was determined by flow cytometry using a monoclonal antibody (2D7) to CCR5. Staining with an isotype control (shaded areas) and with the monoclonal antibody to CCR5 (solid lines) are shown.
also endemic in some of these areas, interaction between the two microorganisms may have clinical significance. In this regard, a recent study from Thailand has reported that scrub typhus infection may suppress HIV-1 infection, which is in striking contrast to many other microbial coinfections that generally result in enhanced replication of HIV-1. However, difficulty in conducting a prospective and well-controlled clinical study in Thailand, as well as the lack of precise laboratory data supporting their hypothesis, has resulted in substantial controversy.

Our in vitro study has suggested that *O. tsutsugamushi* infection had impacts on HIV-1 infection in several different ways, and that the net effect depends upon the balance of positive and negative factors. Difference in the net effects observed among different donors is intriguing and deserves further evaluation. Our preliminary data suggest that a number of host factors are involved in such variability (Moriuchi M, Moriuchi H, unpublished data). For example, while up-regulation of HIV-1 expression from the LTR promoter secondary to proinflammatory cytokine production would benefit HIV-1 infection, down-regulation of CCR5 expression as well as production of chemokines would inhibit HIV-1 entry. Activation of LTR by microbial stimulation has been demonstrated in a variety of other co-infections. We have previously reported similar dichotomous effects of bacterial cell wall components such as lipopolysaccharide (LPS) of gram-negative bacilli, lipoteichoic acid of gram-positive cocci, and lipoarabinomannan of mycobacteria on HIV-1 infection. Our results in the present study were not unexpected, since *O. tsutsugamushi* contains LPS in its cell wall structure, although rickettsial LPS generally has weaker endotoxin activity than that of other gram-negative bacilli. Thus, although it is still possible that in vivo infection with *O. tsutsugamushi* may have substantially distinct effects on HIV-1 infection, our in vitro study suggests that scrub typhus does not necessarily suppress HIV-1 infection and does have potential to enhance HIV-1 replication.

Interactions between HIV and other microbes do not appear to be simple. Recently, measles infection has been shown to suppress HIV viremia in patients, and we have also demonstrated that malaria parasites may suppress HIV-1 infection.

### Table 2

<table>
<thead>
<tr>
<th>Patient</th>
<th>CD4+ T cells (/μL)</th>
<th>HIV-1 RNA copies (mL)</th>
<th>p24 (pg/mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>303</td>
<td>&lt;50</td>
<td>&lt;7.8</td>
</tr>
<tr>
<td>2</td>
<td>238</td>
<td>&lt;500</td>
<td>&lt;7.8</td>
</tr>
<tr>
<td>3</td>
<td>601</td>
<td>&lt;500</td>
<td>&lt;7.8</td>
</tr>
<tr>
<td>4</td>
<td>596</td>
<td>&lt;50</td>
<td>&lt;7.8</td>
</tr>
</tbody>
</table>

Peripheral blood mononuclear cells were derived from patients 1 through 4 whose plasma viremia was undetectable by the Amplicor Ultrasensitive HIV-1 Monitor assay (Roche Diagnostics Corporation, Indianapolis, IN) in patients 1 and 4 or by real-time PCR assay in patients 2 and 3. The PBMC were either unstimulated or stimulated as indicated. Peak HIV-1 p24 titers that were obtained on day 16 are shown. PHA = phytohemagglutinin, IL-2 = interleukin-2. * HIV-1 replication in the PBMC of patient 5, as determined by slight increase in p24 titer on day 16, was not able to be expanded by further passages.

**Figure 4.** Up-regulation of human immunodeficiency virus-1 (HIV-1) long terminal repeat (LTR) activity by *Orientia tsutsugamushi*. Peripheral blood mononuclear cells were transfected with pGL-HIV-1-LTR along with pSV2CAT or pSV-Tat, and stimulated with *O. tsutsugamushi*. Luciferase activity in the transfected cell lysates was determined two days after transfection. Results (mean ± SD) of triplicate experiments are shown.

**Figure 5.** Mediation of the effects of infection with *Orientia tsutsugamushi* on human immunodeficiency virus-1 (HIV-1) infection through soluble activity. Peripheral blood mononuclear cells (PBMC) were infected with a replication-recombinant virus pseudotyped with envelope (env) protein from R5 HIV-1 JRFL or X4 HIV-1 HXB2. The PBMC were not treated, pretreated (pre), or post-treated (post) with supernatants from autologous PBMC infected with the *O. tsutsugamushi* Karp strain, and luciferase activity in the cell lysates was determined. Fold induction indicates luciferase activity relative to that of a control (untreated) experiment. Results (mean ± SD) of triplicate experiments are shown.
tion in vitro. Further studies are required for better understanding of interaction between these microbes and HIV-1 in co-infected patients.

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