Gamma Interferon and Interleukin-10 Gene Expression in Synovial Tissues from Patients with Early Stages of Chlamydia-Associated Arthritis and Undifferentiated Oligoarthritis and from Healthy Volunteers

SHIGERU KOTAKE,† H. RALPH SCHUMACHER, JR.,1,2 THURAYYA K. ARAYSSI,1 HERVE C. GÉRAD,3 PATRICK J. BRANIGAN,4 ALAN P. HUDSON,3 CHERYL H. YARBORO,3 JOHN H. KLIPPEL,4 AND RONALD L. WILDER 1*

National Institute of Arthritis and Musculoskeletal and Skin Diseases, National Institutes of Health, Bethesda, Maryland1; Department of Veterans Affairs Medical Center2 and Department of Microbiology and Immunology, MCP-Hahnemann School of Medicine,4 Philadelphia, Pennsylvania; and Department of Immunology and Microbiology, Wayne State University Medical School, Detroit, Michigan3

Received 28 July 1998/Returned for modification 28 September 1998/Accepted 12 February 1999

Chlamydiae are intracellular bacterial pathogens of eukaryotic cells and are responsible for a wide variety of important human and animal infections (21). Reactive arthritis (ReA) is triggered by infection of the urogenital tract with Chlamydia trachomatis, the upper respiratory tract with Chlamydia pneumoniae, or the gastrointestinal tract with Yersinia, Salmonella, Shigella, or Campylobacter (4). In Chlamydia-associated arthritis (Chl-AA), chlamydial RNA and/or DNA are present in synovial tissues, and organisms are frequently observed by electron microscopic evaluation or in situ hybridization (2, 15). The organisms are hypothesized to act as a proinflammatory foreign body, initiating the clinical response (20). Moreover, a recent report indicated that Chlamydia infection inhibits cell death through apoptosis (6). Cytokines also appear to play important roles in the persistent infection of C. trachomatis. Gamma interferon (IFN-γ), the main cytokine produced by Th1 and NK cells, may have a dual role in chlamydial infection, potentially mediating both host resistance and immunopathology within synovial tissue (20). In support of this hypothesis, a recent study showed that genetically determined differences in IFN-γ and interleukin-10 (IL-10) responses in mice correlated with clearance of Chlamydia pneumoniae infection. We measured the synovial expression of IL-10 and IFN-γ and additional cytokine genes in patients who had recent-onset Chlamydia-associated arthritis (Chl-AA). IL-10 and IFN-γ mRNA were relatively abundant in recent-onset Chl-AA.

Genetically determined differences in interleukin-10 (IL-10) and gamma interferon (IFN-γ) responses in mice correlate with clearance of Chlamydia pneumonia infection. We measured the synovial expression of IL-10 and IFN-γ and additional cytokine genes in patients who had recent-onset Chlamydia-associated arthritis (Chl-AA). IL-10 and IFN-γ mRNA were relatively abundant in recent-onset Chl-AA.
closed-needle biopsy using a Parker Pearson needle from a single tender joint from each patient as previously described (10, 11). Total RNA was prepared from all specimens by the Tri Reagent method. Complementary DNA was synthesized from mRNA by priming total RNA isolated from each whole synovial specimen. We normalized all samples for β-actin cDNA content by competitive PCR and quantitated the amount of each cytokine mRNA in each synovial specimen with a nested PCR technique. The first PCR was conducted with outer sense and outer antisense primers. The nested PCR was conducted with inner sense and inner antisense primers (11). The nested RT-PCR technique is at least 1,000 times more sensitive than a single round of RT-PCR alone and allowed us to analyze each of the small synovial specimens obtained by needle biopsy (11). Polyacrylamide gel electrophoresis of the nested PCR product revealed zero to three bands, depending on the concentration of target cDNA. The relative amounts of each cytokine and CD36 cDNA were graded (+, +, +, +, or 0) on the basis of the pattern of bands generated by nested PCR. Then, the mean value of the mRNA grades of four synovial specimens from a single joint was calculated. The data were analyzed by using the Spearman’s rank correlation coefficient and Mann-Whitney test (StatView: Abacus Concepts Inc., Berkeley, Calif.). A significant difference was defined as P < 0.05.

Figure 1A shows the relative levels of mRNA for proinflammatory cytokines (TNF-α and IL-1β), type 1 cytokines (IL-2, IL-12 p40, IL-15, and IFN-γ), and type 2 cytokines (IL-4, IL-6, IL-10, and IL-13) in each synovial specimen for all NV. We detected IL-10 and IL-15 mRNA in at least one specimen from all NV. IFN-γ mRNA was detected in only two of six NV. Both IFN-γ and IL-10 were detected in NV 2 and NV 3. Interestingly, *C. trachomatis* DNA was also detected in synovial specimens from NV 3, who had no evidence of clinically apparent illness. TNF-α and/or IL-15b mRNAs were detected in specimens from four of the NV. IL-2, IL-4, or IL-13 mRNA was not detected in the NV. Figure 1B and C show cytokine profiles in synovial specimens from all six Chl-AA patients and six representative UO patients, respectively. IFN-γ and IL-10 mRNA were detected in virtually all the specimens from Chl-AA patients. IL-10 mRNA was detected in all of the specimens from patients with UO, while IFN-γ mRNA was not detected in three of the UO patients. TNF-α, IL-1β, IL-6, and IL-15 mRNAs were also frequently detected in Chl-AA patients. IL-2 and IL-12 p40 mRNAs were detected in three of the Chl-AA patients, while IL-4 and IL-13 mRNAs were not detected. Figure 2 shows the relative mRNA levels for IFN-γ and IL-10 for all 35 patients and 6 NV studied. The Chl-AA patients clearly had more IFN-γ and IL-10 mRNA than did UO patients or NV. The levels of IFN-γ and IL-10 mRNA were significantly higher in Chl-AA patients than in UO patients (P = 0.007 and 0.014, respectively) or than in NV (P = 0.011 and 0.033, respectively). The level of IFN-γ mRNA was significantly higher in UO patients than in NV (P = 0.027). The levels of other cytokine mRNAs, including IL-12 p40 and IL-4, did not differ between Chl-AA and UO patients. The levels of CD3 δ-chain mRNA were significantly higher in Chl-AA patients than in UO patients (P = 0.001). These results indicate that the number of T cells was higher in Chl-AA patients than in UO patients, because CD3 δ chain is expressed on the surface of T cells as a part of T-cell receptor. CD3 δ-chain mRNA was also detected in all NV.

The most notable finding in our study was that mRNA levels of both IFN-γ and IL-10 were significantly higher in early Chl-AA patients than early UO patients or NV (Fig. 2). Byrne et al. and Shemer-Avni et al. have reported that IFN-γ functions as a cytotoxic cytokine against *Chlamydia*-infected fibroblasts (5, 16). Rank et al. reported that anti-IFN-γ antibody treatment resulted in significantly prolonged murine chlamydial genital infection and that passive administration of recombinant IFN-γ to chronically infected mice was able to bring about resolution of the infection (14). Thus, their data suggest that IFN-γ may play a role in regulating the growth and differentiation of *Chlamydia* in the tissues. The production of IFN-γ is, however, probably antagonized by the presence of IL-10. Yang et al. have published data supporting the hypothesis that excessive IL-10 production in BALB/c mice inhibits Th1-like responses, including IFN-γ expression and the delayed-type hypersensitivity response following chlamydial infection, and consequently delays resolution of the infection (22). Beatty et al., using an in vitro cell culture system, have demonstrated that the effect of IFN-γ on *Chlamydia* is dose dependent (1). Persistent infection is established with low-dose IFN-γ and is characterized by the development of noninfectious atypical chlamydial forms, atypical reticulate bodies, that show near-normal levels of the 60-kDa heat shock protein, an immunopathologic antigen, and a paucity of the major outer membrane protein, a protective antigen (1). Moreover, Nangara et al. reported *C. trachomatis* infection in synovial tissues from patients who had either early or chronic ReA and that most persistent organisms were atypical reticulate bodies with diminished major outer membrane protein (12). In our study, the levels of IL-10 in the Chl-AA group may have been high because of the corresponding high levels of TNF-α and IL-1.

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age (yr)</th>
<th>Sex</th>
<th>Duration of arthritis (mo)</th>
<th>Chlamydial DNA in synovial tissue</th>
<th>Primary rRNA transcripts</th>
<th>Serum IgG to C. trachomatis</th>
<th>Associated clinical features</th>
<th>HLA-B27</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>22/F</td>
<td></td>
<td>3</td>
<td>+, tr.</td>
<td>-</td>
<td>Low positive</td>
<td>Monoarth.</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>52/M</td>
<td></td>
<td>2</td>
<td>+, tr.</td>
<td>+</td>
<td>-</td>
<td>Oligoarth.</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>19/M</td>
<td></td>
<td>1</td>
<td>+, tr.</td>
<td>-</td>
<td>-</td>
<td>Monoarth.</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>25/F</td>
<td></td>
<td>1</td>
<td>+, tr.</td>
<td>+</td>
<td>-</td>
<td>Monoarth.</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>31/F</td>
<td></td>
<td>5</td>
<td>+, tr. (SF)</td>
<td>-</td>
<td>-</td>
<td>Monoarth.</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>30/F</td>
<td></td>
<td>6</td>
<td>+, tr.</td>
<td>-</td>
<td>-</td>
<td>Oligoarth.</td>
<td>+</td>
</tr>
</tbody>
</table>

* a None had previously received antibiotics.
* b, F, female; M, male.
* c Chlamydial DNA sequences targeted were the 16s rRNA and MOMP genes (3, 8).
* d F, female; M, male.
* e Assays targeting primary transcripts from the chlamydial rRNA operons were performed as described in reference 9. NES, not enough sample.
* f Specialty Laboratories, San Monica, Calif.
FIG. 1. Relative expression levels of cytokine mRNAs in 6 NV (A), 6 Chl-AA patients (B), and 6 representative UO patients of 29 UO patients (C). The relative amounts of mRNA of CD3 ε chain and each cytokine in synovial tissues from each patient were quantitated, and the mean value was calculated as described in the text. The relative amounts of the cytokine mRNAs are shown as 0, 1+, 2+, 3+, and 4+ on the y axis. ND, not done. The numbers on the y axis represent the synovial specimen number from each subject.
fluids of patients with chlamydial ReA yielded a predominantly Th1 cytokine pattern (19). However, later work suggested that this Th1 predominance might have resulted from bias introduced by the cloning procedure or from insensitive methods of detecting the Th2 cytokine IL-4 (4). Simon et al. also reported that IFN-γ mRNA was found in both ReA and RA synovial membranes, while IL-4 mRNA was detected almost exclusively in ReA membranes (4, 18). They also proposed that IL-4 possibly mediates bacterial persistence in the joint by inhibition of IFN-γ effects (17). In contrast, we recently reported that we rarely detected IL-4 mRNA in synovial specimens from patients with early ReA or RA (10). In the present study, we also rarely detected IL-4 mRNA in synovial specimens from patients with Chl-AA (Fig. 1B). Our data suggest that IL-10, rather than IL-4, is the major inhibitor of IFN-γ production and cellular immunity in early Chl-AA, because we detected IL-10 mRNA but neither IL-4 nor IL-13 mRNA in Chl-AA patients (Fig. 1B, 1C, and 2). Our data may differ from those of Simon et al. (18) for several reasons. First, our analytic techniques and synovial tissue procurement differed, and we analyzed only patients with less than 12 months of disease who were taking neither prednisone nor second-line antirheumatic drugs, with or without chlamydial DNA-positive synovial tissues. Simon et al. examined a group of nine ReA patients that included patients with both early and chronic ReA following infection with not only *Chlamydia* but also *Yersinia*, *Salmonella*, *Shigella*, or *Borrelia*. Medications were not mentioned in their study.

More recently, Yin et al. reported that a Th2 cytokine pattern predominates in the joints of patients with ReA, and they suggested that since Th1 cytokines are necessary for the elimination of ReA-associated bacteria, Th2 cytokines might contribute to bacterial persistence in the joint. In addition, they suggested that the IL-10–IL-12 balance is crucial for regulation of the cytokine pattern in the joints of patients with ReA (23). However, in detection of IL-4, our results also differ from those of Yin et al. We observed that IL-4 gene expression was rare in early disease. They reported a relatively higher number of IL-4-positive cells compared with the number of IFN-γ-secreting cells in synovial specimens. Although they studied synovial tissues from the four patients with ReA immunohistologically, three of the patients with Chl-AA had chronic-stage...
disease (durations of 36, 18, and 36 months, respectively). Medications were not mentioned in their study (23).

We also analyzed cytokine mRNA profiles in 24 synovial tissue specimens obtained from 6 NV and compared these data to those for 6 Chl-AA and 29 UO patients taking neither prednisone nor second-line antirheumatic drugs. Cytokine mRNA profiles in NV varied. IL-10 and IL-15 mRNAs were frequently detected, although the amounts of these cytokine mRNAs were smaller than those in synovial tissue from Chl-AA patients (Fig. 1A versus 1B). Thus, our results may indicate that the IL-10 and IL-15 genes are constitutively expressed in the normal synovial tissue. In contrast to the frequent detection of IL-10 and IL-15, IFN-γ mRNA was detected only in synovial specimens from NV 2 and NV 3. Moreover, synovial specimens from NV 3 were Chlamydia trachomatis DNA positive, although the patient did not have clinical symptoms. Thus, the detection of both IL-10 and IFN-γ mRNAs in synovial specimens of NV 3 is similar to the cytokine profile of Chl-AA patients as discussed above. The cytokine profile of NV 3 may represent an asymptomatic and extremely early phase of Chl-AA. We are now following up the clinical and laboratory findings of NV 3 to evaluate this possibility.

In summary, our present study indicates that IFN-γ and IL-10 are relatively abundant in synovial tissue of early Chl-AA patients. We suggest that high IL-10 levels facilitate persistent chlamydial infection of synovial tissue by antagonizing cellular immunity and the generation of IFN-γ-dependent mechanisms required to clear the organism. Our data clearly encourage additional study on the role of host factors in determining the outcome of synovial chlamydial infection.

We express our appreciation to George Poy for oligonucleotide synthesis.

This work was supported in part by NIH grant AR-42541 to A.P.H.

REFERENCES

Editor: R. N. Moore