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Inhibitors of TLR8 Reduce TNF Production from Human Rheumatoid Synovial Membrane Cultures

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The advent of anti-TNF biologicals has been a seminal advance in the treatment of rheumatoid arthritis (RA) and has confirmed the important role of TNF in disease pathogenesis. However, it is unknown what sustains the chronic production of TNF. In this study, we have investigated the anti-inflammatory properties of mianserin, a serotonin receptor antagonist. We discovered mianserin was able to inhibit the endosomal TLRs 3, 7, 8, and 9 in primary human cells and inhibited the spontaneous release of TNF and IL-6 from RA synovial membrane cultures. This suggested a role for these TLRs in production of TNF and IL-6 from RA synovial cultures. Only stimulation of TLR 3 or 8 induced TNF from these cultures, indicating that TLR7 and TLR9 were of less consequence in this model. The key observation that indicated the importance of TLR8 was the inhibition of spontaneous TNF production by imiquimod, which we discovered to be an inhibitor of TLR8. Together, these data suggest that TLR8 may play a role in driving TNF production in RA. Because this receptor can be inhibited by small m.w. molecules, it may prove to be an important therapeutic target.

Rheumatoid arthritis (RA), a chronic autoimmune inflammatory disease affecting 1% of the population, is characterized by a destructive inflammation of the joints, leading to progressive disability and reduced life expectancy. The synovial membrane is infiltrated by activated immune cells, predominantly macrophages and T cells, resulting in the chronic production of proinflammatory cytokines and matrix metalloproteinases. In turn, these factors lead to inflammation and cartilage and bone degradation (1). The treatment of RA has been revolutionized by the development of biological therapies specifically targeting immune mediators. These include IL-1, IL-6R, B cells (anti-CD20), and activated T cells (CTLA4-Ig). Clinically, the most effective therapies are those that target TNF: infliximab; etanercept; and adalimumab (2).

Despite our understanding of the central role played by TNF in RA, it is still unclear what stimuli are involved in driving its chronic production in disease. Potential candidates for this role include ligands of the TLR family. TLRs form part of a network of receptors that detect pathogen-associated molecular patterns and alert the host to the presence of infection. The family of 10 human TLRs identified to date can be classified into 2 distinct groups based on cellular distribution and ligand repertoire. Cell surface expressed TLRs 1, 2, 4, 5, and 6 recognize ligands of bacterial and fungal origin, whereas TLRs 3, 7, 8, and 9 are expressed predominantly in the endosomal compartment and detect mainly viral products (3). The hallmark of TLR activation is the induction of a strong inflammatory response that is characterized by TNF production among many other mediators. In addition to microbial products, TLRs engage a number of endogenous molecules that can be produced during tissue damage (4) and are likely to be found at the sites of chronic inflammation. Candidate endogenous TLR ligands such as heat shock proteins, hyaluronan, and high-mobility group box protein-1 have all been detected in inflamed joints (5) and the expression of TLRs 2, 3, 4, and 7 have been reported in human RA tissue (6–8). Moreover, TLR3 ligands (generated from freeze-thawing synovial fluid cells to induce necrosis) have been shown to activate cultured RA synovial fibroblasts (RASF) (9). The concept of endogenous ligand-driven activation of TLR signaling has raised interest in these receptors as potential candidates in the induction and/or maintenance of chronic inflammatory conditions such as RA (10).

Our recent studies on TLRs in the human RA tissue model have shown that spontaneous production of cytokines from human RA synovial cell cultures is partly dependent on MyD88 and MyD88 adaptor-like (Mal) protein, intracellular adaptor proteins used by TLRs to engage the intracellular signaling network (11). However, there is still no clear evidence on which TLRs are actually contributing to the TNF production in human RA.

We became interested in reports that some serotonin (5-HT) receptor antagonists can inhibit LPS (TLR4 ligand)-induced TNF production from human monocytes (12) and other studies showing anti-inflammatory properties in animal models of inflammation. One particular example is mianserin, a tetracyclic 5-HT2A/C receptor antagonist which has been shown to decrease PMA-induced edema in the mouse (13) and B1 kinin receptor-induced paw edema formation in rodents (14).
In this study, we observed in primary human cells that mianserin did not inhibit TLR4 activation but was an inhibitor of the endosomal TLR 3-, 7-, 8-, and 9-mediated cytokine production. Moreover, addition of mianserin significantly reduced the spontaneous TNF and IL-6 production from human rheumatoid synovial membrane cultures. Further studies suggested that the suppressive effect on TNF from the human RA membrane cultures might be mediated at least in part through the inhibition of TLR8.

### Materials and Methods

#### Reagents

Cell culture reagents used were: penicillin-streptomycin, RPMI 1640, and DMEM obtained from Cambrex; indomethacin and cycloheximide from Sigma-Aldrich; and PBS from PAA. The TLR ligands used were chloroform-extracted Escherichia coli, LPS, resiquimod (R-848), loxoribine, ss-RNA (RNA40/Lyovec), CpG (oligodeoxynucleotide 2006), and imiquimod from Invivogen. Flagellin (purified) and Pam3Cys-Ser(Lys)4 (Pam3) were from Alexis. Methylmercury hydrochloride was purchased from Sequoia Research Products. Chloroquine diphosphate salt was purchased from Sigma-Aldrich. The Abs used for FACS were FITC-conjugated anti-TLR3, anti-TLR8, and anti-TLR9 from Imgenex and an IgG1-FITC control from BD Pharmingen. The 25-D1.16 Ab used to detect SINFEKL expression was a gift from Professor Ping Wang and Salah Mansour (Institute of Cell and Molecular Science, Queen Mary School of Medicine, University of London, London, U.K.). The Abs used for Western blotting were anti-tubulin Ab from Sigma-Aldrich; Abs recognizing phosphorylated forms of JNK (p46/p54), p38, and ERK (p42/p44) from Cell Signaling Technology. Human CD19 microbeads were purchased from MACS Miltenyi Biotech. All reagents were tested for LPS using the Limulus amebocyte lysate assay from Cambrex (15) and were found to have no detectable levels of LPS.

#### Cell culture

RA synovial membrane cells were isolated from patients undergoing joint replacement surgery as previously described (16, 17). Immediately after isolation, cells were used for mRNA analysis, stained by FACS, or cultured at 1 × 10⁵ cells/well in 96-well tissue culture plates (Falcon) in RPMI 1640 containing 5% (v/v) FBS and 100 U/ml penicillin-streptomycin. All patients gave written informed consent, and the study was approved by the local ethics committee. Primary human RASFs and PBMCs were isolated from Synovial biopsy samples. RASFs were isolated by one-step real-time quantitative RT-PCR, after which 5 × 10⁸ macrophages were pretreated with mianserin or imiquimod for 30 min and then stimulated with 10 ng/ml LPS or 1 μg/ml R-848 for 2 h. Total RNA was then extracted using the RNeasy Blood (Qiagen) kits according to the manufacturer's protocols. Real-time quantitative RT-PCR was performed on a StepOnePlus instrument (Applied Biosystems) using the TaqMan RNA-to-Ct 1-Step Kit (Applied Biosystems) and Assay-On-Demand premixed TaqMan probe master mixes (Applied Biosystems). Each RNA sample was run in triplicate, and relative gene expression was calculated using the ΔCt/ΔCt method (21), with GAPDH as the comparator.

#### Western blotting

Human M-CSF macrophages were precultivated with mianserin for 30 min before stimulation with TLR ligands used at previously determined optimum concentrations. Cell extracts were prepared in 100 μl of lysis buffer (1% Nonidet P-40, 150 mM NaCl, 20 mM Tris, pH 7.5) containing 10 mM EDTA, 10 mM EGTA, 1 mM Na3VO4, 5 mM NaF, and a protease inhibitor mixture (Sigma-Aldrich). Extracts were separated on 10% SDS-PAGE gels, and proteins were transferred to polyvinylidene difluoride membrane. Membranes were blocked in 2% BSA in Tris-buffered saline containing 0.1% Tween 20 (TBST) and sequentially probed with Abs recognizing phosphorylated forms of JNK (p46/p54), p38, and ERK (p42/p44). Blots were stripped of Ab between analysis using Re-blot (Chemicon) and blocked again in 2% BSA-TBST.

#### ELISA

Sandwich ELISAs were used to measure TNF and IL-6 (BD Pharmingen). Optical density was read on a spectrophotometric ELISA plate reader (Lab systems Multiscan Biochromic) and analyzed using Ascent software V2.6 (Thermo Labsystems). Cell viability was not significantly affected over this time period when examined by the MTT assay from Sigma-Aldrich (22).

#### Luciferase assay

Macrophages and RASFs were infected with a recombinant adenovirus containing an NF-κB luciferase reporter gene (kindly provided by Dr. B. Davidson, University of Iowa, Ames, IA) at a multiplicity of infection of 50:1 for macrophages or 250:1 for RASFs. After 24 h, cells were stimulation for 6 h with filtered RA supernatants. The cells were washed once in PBS and lysed with 100 μl of CAT lysis buffer (0.65% (v/v) of Nonidet P-40, 10 mM Tris-HCl (pH 8), 0.1 mM EDTA (pH 8), and 150 mM NaCl). Fifty microliters of cell lysate were mixed with 120 microliters of luciferase assay buffer (25 mM Tris-phosphate (pH 7.8), 8 mM MgCl₂, 1 mM EDTA, 1% (v/v) Triton X-100, 1% (v/v) glycerol, 0.1 mM DTT, 0.5 mM ATP) in the well of a luminometer cuvet strip. Luciferase activity was measured with a Luminometer (Thermo Labsystems) by adding 30 μl of luciferin (Bright-Glo luciferase assay system; Promega) per assay point.

#### Flow cytometry

Cells were washed, then blocked with 10% human serum in PBS containing 0.01% azide for 30 min at 4°C, or for intracellular staining cells were fixed in 2% paraformaldehyde and permeabilized with 0.1% saponin (Sigma-Aldrich) before blocking. Cells were then incubated with FITC-conjugated anti-TLR3, anti-TLR8, anti-TLR9, or isotype controls for 1 h at 4°C and then washed before analysis on a BD Biosciences LSR flow cytometer.

#### Statistical methods

Mean, SD, SEM, and statistical significance were calculated using GraphPad version 3 (GraphPad Software). For statistical analysis, a one-tailed t test of paired data was used with a 95% confidence interval or a Wilcoxon matched-pairs two-tailed signed ranks test. SEM was used for pooled experimental data, whereas SD was used in graphs showing representative experiments. ***, p < 0.001; **, p < 0.01; and *, p < 0.05.

### Results

Mianserin inhibits TLR 3-, 7-, 8-, and 9-induced cytokine production in primary human cells

We tested the ability of mianserin to inhibit TLR function in primary human cells. Mianserin had no effect on TLR1/2, 4, or 5 activity (Fig. 1A) but was found to selectively inhibit R-848 (TLR7/8; Ref. 23) induced TNF production from human macrophages (Fig. 1A) in a dose-dependent manner (Fig. 1B). Further investigation in macrophages revealed that mianserin significantly inhibited the activation of NF-κB by R-848 but not in cells stimulated with LPS (Fig. 1C). Mianserin also inhibited the expression

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Mianserin inhibits phosphorylation of early signaling molecules activated by R-848 in primary human macrophages and competitively inhibits R-848. A. Macrophages were stimulated with 1 μg/ml R-848 or 10 ng/ml LPS for 0, 5, 15, 30, 60, or 90 min. Cells lysates were examined for p38 phosphorylation and tubulin as a loading control. B. Cells were either unstimulated or incubated with mianserin for 30 min and then stimulated with 1 μg/ml R-848 for 30 min or 10 ng/ml LPS for 15 min. Lysates were examined for phosphorylation of p54, p38, and p42/44 with tubulin as a loading control. Data are representative of three separate experiments from three unrelated donors. C. Macrophages were incubated with medium containing 0.3, 1, 10, or 20 μg/ml R-848 with medium alone or in the presence of 5 μg/ml mianserin for 6 h. Data were pooled from three separate donors.

Inhibitory effects of mianserin suggest a role for TLRs in TNF and IL-6 production from RA synovial membrane cultures

Given the inhibitory effect of mianserin on TLRs 3, 7, 8, and 9, we were interested in what effect this drug would have on TNF production in the RA synovial cultures. These cultures are mixed populations of cells that spontaneously release cytokines (11) without the need for exogenous stimulation and are considered an accepted model of human disease. This model was used for the initial studies that identified the importance of TNF in RA (16).

Our previous study (11) suggested a role for TLR signaling in driving TNF and IL-6 production in RA synovial membrane cultures. In light of the data in Fig. 1, and because we were unable to find evidence for a contribution from TLR2 or TLR4, we investigated mianserin in this model. Mianserin was found to dose dependently inhibit spontaneous production of TNF and IL-6 from RA synovial membrane cultures without any effect on cell viability.
Mianserin and chloroquine inhibit spontaneous cytokine production from RA synovial membrane cultures. A, RA synovial membrane cells were cultured for 24 h in the presence of 0, 10, 20, or 30 μg/ml mianserin. Supernatants were analyzed for TNF and IL-6, and cell viability was measured by a MTT assay. Data are from triplicate cultures and are representative of three separate experiments. B, RA synovial membrane cells from 12–18 donors were cultured for 24 h in the presence of medium alone or medium containing 30 μg/ml mianserin. C, RA synovial membrane cells from six to seven donors were incubated with 0, 10, or 100 μM chloroquine for 24 h. D, M-CSF-derived human macrophages and RASFs were infected with NF-κB reporter virus. After 24 h, cells were pretreated with 30 μg/ml mianserin for 30 min and then stimulated for 6 h with filtered supernatants harvested from RA synovial membrane cell cultures. Cells were then lysed and luciferase activity was measured. Data are shown as fold induction (±SEM) from pooled data from three to four RA donors.

FIGURE 3. Mianserin and chloroquine inhibit spontaneous cytokine production from RA synovial membrane cultures. A, RA synovial membrane cells were cultured for 24 h in the presence of 0, 10, 20, or 30 μg/ml mianserin. Supernatants were analyzed for TNF and IL-6, and cell viability was measured by a MTT assay. Data are from triplicate cultures and are representative of three separate experiments. B, RA synovial membrane cells from 12–18 donors were cultured for 24 h in the presence of medium alone or medium containing 30 μg/ml mianserin. C, RA synovial membrane cells from six to seven donors were incubated with 0, 10, or 100 μM chloroquine for 24 h. D, M-CSF-derived human macrophages and RASFs were infected with NF-κB reporter virus. After 24 h, cells were pretreated with 30 μg/ml mianserin for 30 min and then stimulated for 6 h with filtered supernatants harvested from RA synovial membrane cell cultures. Cells were then lysed and luciferase activity was measured. Data are shown as fold induction (±SEM) from pooled data from three to four RA donors.

Chloroquine and its derivatives are used to treat chronic inflammatory conditions such as RA, although the mechanism of action is unclear (27). They inhibit endosomal acidification, a prerequisite for activation of TLRs 3, 7, 8, and 9 (28–31). Because mianserin inhibits TLR3, 7, 8, and 9, which are localized to the endosome, and was able to inhibit TNF and IL-6 from RA cultures, we were interested in whether inhibition of the endosomal TLRs by chloroquine would also inhibit these cytokines in RA synovial membrane cultures. At 10 and 100 μM chloroquine, TNF production was inhibited by 51.4 ± 9.6% (p = 0.0065) and 82.3 ± 3.25% (p < 0.0001), respectively, and IL-6 by 46.1 ± 25.6% (p = 0.0074) and 89.8 ± 4.8% (p = 0.0065; Fig. 3C). These data are consistent with a role for these TLRs in TNF production from RA synovial membrane cultures.

FIGURE 4. TLRs 3, 7, 8, and 9 are expressed in the rheumatoid synovial membrane.

Mianserin inhibits activation of NF-κB stimulated by conditioned medium from rheumatoid synovial cell cultures

We have previously shown that conditioned medium from RA synovial cell cultures contains a ligand(s) that activates NF-κB in human macrophages in a MyD88- and Mal-dependant manner (11), but it was unclear which TLR(s) were being activated. Because mianserin is able to inhibit spontaneous cytokine release from RA membrane cultures we tested whether it could inhibit NF-κB activation induced by supernatants from RA cultures. Synovial cell culture supernatants were collected from cultures after 24 h and filtered to remove any cell debris. These supernatants were tested for LPS and found to be free from contamination. Supernatants were used to stimulate M-CSF-derived macrophages and RASFs expressing a consensus sequence NF-κB reporter gene. NF-κB activity was used as a readout as the supernatants used to stimulate the macrophages contain cytokines. The supernatants induced activation of NF-κB that was inhibited by mianserin by 74.7 ± 23.5% (p = 0.1138) in macrophages and by 66.7 ± 9.7% (p = 0.0411) in RASFs.

Rheumatoid synovial membranes display a differential response to ligands for TLRs 3, 7, 8, and 9

Given the above data, we wanted to confirm the expression and function of TLRs 3, 7, 8, and 9 in RA synovium. Using RT-PCR (Fig. 4A) and FACS (Fig. 4B) when suitable Abs were available, RA synovial cells were examined for the expression of TLRs 3, 7, 8, and 9. All were expressed, and TLRs 3, 8, and 9 were predominantly intracellular in agreement with previous studies in other cell types. We have previously shown the expression of TLR2 and 4 in this tissue (11). The synovial membranes were also tested for the ability to respond to exogenously added TLR ligands. As shown in Fig. 5, R-848 (TLR7/8) produced the largest increase in

FIGURE 4. TLRs 3, 7, 8, and 9 are expressed in the rheumatoid synovial membrane.
Imiquimod inhibits activation of TLR8 signaling. A, Structure of R-848, a TLR7/8 ligand, and imiquimod, a TLR7 ligand. B, Primary human M-CSF macrophages were incubated with 10 μg/ml imiquimod alone or in combination with 10 ng/ml flagellin, 10 ng/ml Pam3, 1 μg/ml R-848, or 10 ng/ml LPS for 6 h. Data are pooled from three separate donors as a percentage of the appropriate maximal response (100%). C, Macrophages were incubated with 1 μg/ml R-848 alone or in combination with 2.5, 5, or 10 μg/ml imiquimod for 6 h. Data are from triplicate wells ± SEM. D, Macrophages were preincubated for 30 min with 10 μg/ml imiquimod and then stimulated with 10 ng/ml LPS or 1 μg/ml R-848 for 2 h, after which the TNF message was measured by quantitative PCR. Data are pooled from three separate donors ± SD. E, RASFs were incubated with medium alone or medium containing 20 μg/ml poly(IC) in the presence or absence of 10 μg/ml imiquimod for 6 h. Data show triplicate cultures ± SD and are representative of three separate donors.

Imiquimod inhibits TLR8 activity on human macrophages

The surprising observation that the TLR7 agonist imiquimod inhibited TNF in RA synovial membrane cultures warranted further investigation. Imiquimod is structurally very similar to R-848, having the same core structure but with a slight modification to the side chains (Fig. 6A). We therefore considered the possibility that imiquimod could act as an antagonist of TLR8 activity. Imiquimod inhibited TNF production induced by R-848 (Fig. 6B), an effect that was dose dependent (Fig. 6C) and statistically significant over multiple donors. In contrast, the drug had no effect on TNF production induced from macrophages by LPS (TLR4), Pam3 (TLR1/2), or flagellin (TLR5; Fig. 6B). Further investigation revealed that imiquimod inhibited R-848 but not LPS-induced expression of TNF message in macrophages (Fig. 6D). TLR3 induction of IL-6 from RASF was also not inhibited by imiquimod (Fig. 6E).

The TLR7 ligandloxoribine does not inhibit TLR8 and does not inhibit TNF production from RA synovial membrane cultures

Activation of TLR7 by imiquimod could account for the inhibition of TLR8 signaling. To investigate this possibility, we performed similar experiments in human macrophages and RA synovial membrane cultures using a different TLR7 ligandloxoribine which has less structural similarity to R-848 (Fig. 7A). Loxoribine did not inhibit TNF production from human macrophages induced by R-848 or LPS (Fig. 7B) and had no effect on the spontaneous release of TNF from the RA membrane cultures (Fig. 7C). Alternatively, we also sought to determine whether both imiquimod and mianserin could inhibit an activator of TLR7/8 other than R-848. We used ssRNA and found that both mianserin and imiquimod were able to inhibit TNF production in human macrophages (Fig. 7D).
Mianserin inhibits SIINFEKL presentation on the surface of EG7 cells

Mice expressing a mutation in the endosomal protein UNC93b1 have been demonstrated to have a defect in activation of TLRs 3, 7, and 9 and in the presentation of OVA SIINFEKL peptide on the cell surface of dendritic cells (33). Because mianserin is able to inhibit activation of the same TLRs, UNC93b1 is an attractive candidate target for mianserin. Because it was not possible to investigate a direct interaction between mianserin and UNC93b1, instead we examined whether mianserin would also affect SIINFEKL peptide presentation in murine EL4 cells transfected with chicken OVA cDNA (EG.7 cells). SIINFEKL presentation was measured by FACS. Cycloheximide was used as a control to prevent expression of OVA in EG.7 cells. Mianserin dose dependently inhibited cell surface expression of SIINFEKL peptide, reaching statistical significance at 30 μg/ml mianserin (Fig. 8).

Discussion

TLRs have been suggested to potentially contribute to the pathogenesis of many autoimmune diseases and have thus become prime candidates as targets for new therapeutics (34). In this study, we set out to investigate the anti-inflammatory effect of mianserin and have identified this drug as an inhibitor of the endosomal TLRs 3, 7, 8, and 9 in primary human cells. Mianserin also inhibited the spontaneous release of TNF and IL-6 from RA synovial membrane cultures. Furthermore, these results were supported by the actions of chloroquine, an inhibitor of the endosomal TLRs, which also inhibited TNF and IL-6 in RA cultures and by imiquimod (shown here to be a TLR8 inhibitor), which also significantly inhibited TNF production in the RA synovial membrane cultures, thus suggesting a potential role for endosomal TLRs and in particular TLR8 in RA.

There are several observations from in vivo inflammatory models that mianserin exhibits anti-inflammatory activity (13, 14); however, the mechanism is not known. Our data indicate that the drug blocks the function of the intracellularly located TLR3, TLR7, TLR8, and TLR9 but not the cell surface-located TLRs 1/2, 4, and 5. A potential mechanism by which mianserin may have inhibited the TLRs was possibly through its known effect on 5-HT uptake. A potential mechanism by which mianserin may have inhibited the TLRs was possibly through its known effect on 5-HT uptake. Mianserin dose dependently inhibited cell surface expression of SIINFEKL peptide, reaching statistical significance at 30 μg/ml mianserin (Fig. 8).

In a previous study, we demonstrated that conditioned medium collected from RA cultures contained a potential TLR ligand(s) (11). Mianserin inhibited activation of NF-κB in macrophages stimulated with conditioned medium from RA cultures, suggesting there may be a role for the endosomal TLRs, but probably not TLR3, since poly(IC) activation of TLR3 does not activate NF-κB in human macrophages (24). Activation of NF-κB in RASFs by conditioned supernatants was also inhibited by mianserin. TLRs 7, 8, and 9 are not expressed in RASFs (41), thus suggesting the possibility of a TLR3 ligand in the medium. This hypothesis is supported by the observations of Brentano et al. (9), who demonstrated how apoptotic synovial fluid cells release an endogenous ligand that can stimulate RASFs via TLR3.

Further data indicating a role for TLR3s 3 and/or 8 came from a short oligodeoxynucleotide. A recent study has shown that phosphothioate modification of oligodeoxynucleotides transforms them
to become inhibitors of TLRs 7 and 9 and that this inhibitory action is sequence independent instead requiring the modification of the sugar backbone (42). We identified a phosphothioate oligodeoxynucleotide that inhibited TLRs 3 and 8 in primary human cells and was also able to significantly inhibit spontaneous TNF production from the RA synovial membrane cultures (data not shown). In agreement with the publication by Hass et al., this effect appeared to be sequence independent making it hard to control for experimentally.

The key observation that indicated TLR8 as being important in driving TNF in RA synovial cultures came from the TLR7 agonist imiquimod (32). We discovered that imiquimod could inhibit the activation of TLR8, conceivably due to the similarities in the core structure of R-848 and imiquimod. The ability of imiquimod and mianserin to inhibit TLR8 in macrophages was not restricted to R-848 stimulation; similar results were observed with a more physiologically relevant TLR7/8 ligand ssRNA. The ability of imiquimod to inhibit TLR8-induced TNF did not appear to be mediated through activation of TLR7, given that another TLR7 agonist loxoribine was unable to do this. When added to RA synovial membrane cultures, imiquimod inhibited the spontaneous release of TNF by half whereas loxoribine had no effect. Interestingly, unlike mianserin, imiquimod did not inhibit IL-6 production in RA cultures, which may reflect that IL-6 is being produced by one of the other TLRs inhibited by mianserin, possibly TLR3. Activation of TLR3 on synovial fibroblasts leads to high levels of IL-6 production (24).

In the human RA synovial membrane culture system we have previously demonstrated that overexpression of dominant negative versions of MyD88 and Mal suppressed the expression of TNF and IL-6. Although MyD88 is used by all TLRs (except TLR3), Mal is only used by TLR2 and 4 (11). However, we found that neutralizing Abs to TLR2 and 4 failed to inhibit cytokine production in human RA synovial membrane cultures (43). Taken together, the data with mianserin, chloroquine, and imiquimod suggest that TLR8 may be an important contributor to TNF production in human disease. A role for TLR3 is consistent with our previous study with dominant negative MyD88, because this construct also blocks TLR8 function in human macrophages (43). TLR7 and TLR9 do not appear to be involved in this RA model because they are unable to stimulate TNF production.

The other target of mianserin, TLR3, does induce TNF production in RA synovial membrane cultures, and previously we have observed that stimulation of TLR3 can induce low levels of TNF production from RASFs, a major constituent of these cultures (24). A role for TLR3 could explain the unaccounted effect of the Mal dominant negative, because unlike the other TLRs, TLR3 does not use MyD88 but TLR3 signaling in RASF can be blocked by the Mal dominant negative (manuscript in preparation). However, a role for Mal still leaves the possibility of a contribution from TLRs 2 or 4. Investigation of the precise contribution of TLRs 2, 3, and 4 to the stimulation of TNF and IL-6 production will require more specific reagents. We have been unable to achieve small interfering RNA-targeted knockdown of genes in mixed populations of primary cells as found in the RA synovial membrane cultures.

In summary, these data suggest that TLR8 may be an important contributor to TNF production in RA with a potential contribution from TLR3, although they are certainly not the only factors. Unlike systemic cytokine blockade, inhibiting TLR8 should not lead to an impairment of signaling by the other TLRs or the total inhibition of cytokine function by other signaling mechanisms. Because TLR8 is amenable to inhibition with small m.w. molecules, this receptor may provide a new target for the treatment of RA, bringing potential benefits in safety, in addition to the lower cost and ease of administration provided by oral drugs.

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Disclosures
The authors have no financial conflict of interest.

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