Lymphocytes bearing Fcγ receptors in rheumatoid arthritis. III. Immunoregulatory function associated with Facb rosette-forming cells

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SUMMARY A subpopulation of mononuclear cells (PBMNC) that express Fc receptors with specificity for the Cy2 region of IgG may be detected by rosette formation with calf erythrocytes coated with the Facb fragment of rabbit IgG. These Facb-R⁺ cells are found in increased numbers in the peripheral blood of patients with rheumatoid arthritis (RA). Studies have been carried out to identify the functional properties of these cells in healthy and rheumatoid subjects. Facb-R⁺ cells were shown to lack both natural killer and antibody-dependent cytotoxic activity. Depletion of Facb-R⁺ cells from both healthy and rheumatoid PBMNC resulted in a marked suppression of pokeweed mitogen (PWM) stimulated IgG synthesis but had no effect on T cell proliferation induced by phytohaemagglutinin, concanavalin A, or PWM. The addition of Facb fragments to PBMNC cultures also caused inhibition of PWM-driven IgG production. In this assay rheumatoid PBMNC were significantly less sensitive to Facb-mediated suppression than healthy control cells. Our results suggest that Facb-R⁺ cells are involved in the antibody-mediated feedback regulation of immunoglobulin synthesis and that this mechanism is impaired in patients with RA.

Key words: rheumatoid arthritis, antibody synthesis, feedback inhibition, Fc receptor.

The accompanying paper† describes the surface marker expression of a subpopulation of Fc receptor (FcR)-bearing mononuclear cells which may be identified by their ability to form rosettes with Facb-coated calf red blood cells (CRBC). These Facb-R⁺ cells have been found in increased numbers in the peripheral blood of patients with rheumatoid arthritis.² Facb-R⁺ cells lack conventional markers of T and B lymphocytes but express certain antigens, including OKM1 and HLA-DR, which may also be detected on monocytes.³ The pattern of surface phenotype observed for Facb-R⁺ cells is therefore similar to that described for L cells,³-⁵ although Facb-R⁺ cells are clearly associated with a monocytic lineage.

A number of functions have been ascribed to this class of non-T, non-B, FcR⁺ cells. These include both natural killing and antibody-dependent cellular cytotoxicity⁴-⁶ and regulatory effects on lymphocyte activity. The latter include the stimulation of lymphocyte proliferation⁷-⁹ and both enhancing and suppressive effects on antibody production.⁵ In this report the properties of Facb-R⁺ cells from both healthy individuals and rheumatoid patients have been investigated in a variety of assays of lymphocyte function.

Materials and methods

Patient selection and mononuclear cell preparation. Mononuclear cells (PBMNC) were prepared from heparinised peripheral blood samples taken, with informed consent, from healthy volunteers and from patients with classical or definite rheumatoid arth-
ritis, as described in the accompanying paper. PBMC were separated by density flotation over Ficol-Paque (Pharmacia). Preparation and use of Facb fragment. Facb fragments were prepared by plasmin digestion of a purified IgG fraction of rabbit anti-CRBC, and PBMC expressing surface receptors for the Facb portion of IgG were detected by a rosette assay as previously described. In some experiments PBMC were depleted of Facb-R⁺ cells as follows: PBMC were incubated at a final concentration of 1 x 10⁶/ml with an equal volume of 1% v/v Facb-sensitised CRBC on ice for 1 hour. Rosetted cells were separated from unrosetted cells by density flotation over Ficol-Paque. Unrosetted cells were considered Facb-depleted only after testing by re-rosetting with Facb-sensitised CRBC. As a control total PBMC were sham-depleted with non-sensitised CRBC. Lymphocyte proliferation. The effects of addition of Facb fragment and of depletion of Facb-R⁺ cells on proliferative responses of PBMC to certain mitogens were examined. Cells were cultured in 200 µl aliquots of RPMI 1640 (Gibco) at a concentration of 5 x 10⁶/ml. The culture medium contained 10% heat-inactivated fetal calf serum (Gibco), 4 mM glutamine, and 100 U/ml penicillin-streptomycin (Gibco). Quadruplicate cultures of PBMC were aliquoted into round-bottomed microtitre plates (Nunc). In order to achieve optimal mitogenic stimulation three separate dilutions of concanavalin A (con A, Sigma), phytohaemagglutinin (PHA, Gibco), and pokeweed mitogen (PWM, Gibco) were used. Cell cultures were incubated for 68 hours at 37°C in humidified air containing 5% CO₂. Subsequently each culture was supplemented with 0.5 µCi ³H-thymidine (specific activity 5 Ci/mmol, Amer- sham). After a further 4 hours at 37°C the cells were harvested and the uptake of radioisotope measured by liquid scintillation spectrometry. PWM-driven immunoglobulin synthesis. Duplicate cultures of PBMC (1 x 10⁶/ml in RPMI 1640 supplemented as above) were set up in sterile culture plates (Nunc). Cultures (volume 1 ml) contained either total PBMC or PBMC depleted of Facb-R⁺ cells by rosetting. Cells received either no mitogen or a 1:200 dilution of PWM (Gibco) in calcium- and magnesium-free salt solution (CMFSS). Cells also received varying amounts of rabbit Facb fragment (0–15 µg/ml). After incubation for seven days at 37°C the supernatants were harvested and stored at −70°C until analysed for IgG content. Enzyme-linked immunosorbent assay (ELISA). Polystyrene Gilford system cuvettes were coated with sheep polyvalent antihuman immunoglobulins (Sigma). After washing, doubling dilutions of either test supernatants or standard IgG preparations were added. After one hour at 37°C and a further washing step an optimum dilution of rabbit antihuman IgG conjugated to alkaline phosphatase (Sigma) was added. A further incubation and final wash cycle were followed by addition of developing substrate (disodium p-nitrophenol phosphate). Absorbance readings were taken from each well at 405 nm (Gilford EIA Manual Reader) and concentrations of IgG in the supernatants estimated from the standard curve. Cytotoxicity assays. Natural killer (NK) assays were performed on total PBMC cultures and those depleted of Facb-R⁺ cells. The method used was a variation of that used by Pape et al. Cells from the erythroleukaemic line K562 were maintained in RPMI 1640 medium supplemented as above. Washed cells (3 x 10⁶/ml) were labelled with ⁵¹Cr by incubation with 100 µCi Na⁵¹CrO₄ (Amersham) for one hour at 37°C and washed three times before use as targets. The assays were performed in plastic LP3 tubes (Luckham). Target cells were adjusted to a concentration of 2 x 10⁶/ml and 250 µl added to an equal volume of PBMC at a final concentration of 1-2 x 10⁶ or 6 x 10⁵ cells/ml giving a lympho- cyte:target ratio of either 60:1 or 30:1. After incubation for 16 hours at 37°C the cells were sedimented by centrifugation at 200 g for 10 minutes. Radioactivity present in the pellet and supernatant was measured in a gamma-counter (LKB Wallac) and the amount of specific cytotoxicity expressed as a percentage of ⁵¹Cr released from the target cells corrected for spontaneous release from K562 cells cultured in medium alone. Antibody-dependent cytotoxicity (K cell activity) of PBMC and Facb-R⁺ depleted cells was investigated using the method of Panayi and Corrigall. IgG-coated Chang cells labelled with ⁵¹Cr as above were used as targets. Results Immunoglobulin synthesis. When increasing amounts of Facb fragment were added to PWM-stimulated PBMC cultures, a dose-dependent suppression of IgG production resulted (Fig. 1). The data demonstrate that this suppression was significantly less marked in cultures from patients with RA than in cultures from age and sex-matched controls (p<0.01, Mann-Whitney U test). Baseline levels of IgG production, i.e., responses to PWM without addition of Facb fragment, were lower in the rheumatoid cell cultures (933 ± 1109 ng/ml) than in healthy control cultures (1236 ± 1230 ng/ml), but this difference was not statistically significant in these experiments. Responses to Facb fragment were very similar in all control cultures tested, but cells from
two of the 10 rheumatoid patients failed to suppress antibody production irrespective of the dose of Facb fragment added.

The possible mechanisms underlying the Facb-mediated suppression of antibody production were studied by investigating the effect of Facb-R+ cell depletion on PWM-stimulated IgG synthesis. As illustrated in Table 1, this procedure led to a marked inhibition of IgG production by both healthy and rheumatoid PBMNC. The addition of Facb fragment to cultures of Facb-R+ depleted PBMNC had no further effect. The low levels of IgG synthesis by these cells were not caused by a loss of monocytes, since significant numbers of these cells remained in the preparation as identified by non-specific esterase staining.

Lymphocyte proliferation. The depletion of Facb-R+ cells from PBMNC cultures had no signific-

Table 1  The effects of Facb-R+ cell depletion and the addition of Facb fragments on PWM-driven IgG production by PBMNC

<table>
<thead>
<tr>
<th>Source of PBMNC</th>
<th>% PWM-driven IgG production</th>
<th>Facb</th>
<th>+ Facb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy controls (n=6)</td>
<td>Non-depleted</td>
<td>100</td>
<td>32±9</td>
</tr>
<tr>
<td></td>
<td>Facb-R+ depleted</td>
<td>46±19</td>
<td>52±18</td>
</tr>
<tr>
<td>RA patients (n=5)</td>
<td>Non-depleted</td>
<td>100</td>
<td>64±9</td>
</tr>
<tr>
<td></td>
<td>Facb-R+ depleted</td>
<td>31±16</td>
<td>28±14</td>
</tr>
</tbody>
</table>

Results are presented as the mean±SEM IgG production expressed as a percentage of the response in non-depleted cultures (=100%). Rabbit Facb fragment was added at a final concentration of 1·5 µg/ml.

Table 2  Effect of Facb-R+ cell depletion on mitogen-induced lymphocyte proliferation

<table>
<thead>
<tr>
<th>Mitogen</th>
<th>Non-depleted</th>
<th>Facb-R+ depleted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Con A</td>
<td>10 µg/ml</td>
<td>50 µg/ml</td>
</tr>
<tr>
<td>PWM</td>
<td>1:2000</td>
<td>1:400</td>
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<tr>
<td>PWM</td>
<td>1:2000</td>
<td>1:400</td>
</tr>
<tr>
<td>PWM</td>
<td>1:2000</td>
<td>1:400</td>
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</tbody>
</table>

Results are presented as 3H-thymidine incorporation (cpm/105 PBMNC) and are the mean±SEM of six experiments using rheumatoid cells. Similar data (not shown) were obtained in eight experiments using healthy control PBMNC.
Table 3  The effect of Facb-R+ cell depletion on NK cytotoxicity of PBMNC

<table>
<thead>
<tr>
<th>PBMNC</th>
<th>60:1</th>
<th>30:1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-depleted</td>
<td>20±8±7·2</td>
<td>16±4±6·1</td>
</tr>
<tr>
<td>Facb-R+ depleted</td>
<td>20•9±11·4</td>
<td>18±1±9·0</td>
</tr>
</tbody>
</table>

Results are presented as the mean ± standard deviation of five experiments. The spontaneous $^{51}$Cr release from the target cells was 23.3±1.3%.

Fig. 2  Antibody-dependent cellular cytotoxicity of PBMNC fractions at various effector : target cell ratios. Results are presented as % specific $^{51}$Cr release (corrected for release in the absence of antibody). Data points represent the mean ± standard deviation of seven experiments. ○—○ PBMNC; —— O; Facb-R+ depleted PBMNC; Δ—Δ FacR+ depleted PBMNC.

Discussion

Mononuclear cells expressing FcR have been shown to mediate a number of functions including natural and antibody-dependent cytotoxicity and both enhancing and suppressive effects on lymphocyte function. Although forming part of the FcR+ population, Facb-R+ cells do not exhibit cytotoxic activity. This supports the conclusion drawn from the surface phenotype analysis, namely, a lack of identity between Facb-R+ cells and the L cell population described by Horwitz and coworkers. The lack of cytotoxic activity by Facb-R+ cells is also consistent with the observations of elevated levels of these cells, but normal NK function and ADCC in rheumatoid peripheral blood.

Our results indicate a role for Facb-R+ cells in certain lymphocyte responses involved in antibody synthesis but not others such as T cell proliferation. The ability of Facb fragments to inhibit PWM-driven IgG synthesis might be due to the activation of a suppressor mechanism or to the blocking of a positive, accessory function of Facb-R+ cells. These possibilities were investigated by depleting PBMNC of Facb-R+ cells before culture. Removal of a suppressor population should result in enhanced IgG production, whereas loss of accessory cells would diminish antibody synthesis. Our results clearly indicate that Facb-R+ cells are necessary for PWM-stimulated IgG production and that this function may be blocked by Facb fragments. The addition of Facb fragments to Facb-R+ depleted cell cultures had no effect, supporting the assumption that their effect is mediated via Facb-R+ cells. Depletion of Facb-R+ cells did not result in a significant loss of monocytes as judged by staining for non-specific esterase. The ‘accessory’ function of Facb-R+ cells is consistent with the demonstration of class II MHC antigens (HLA-DR) on these cells a property shared by all antigen-presenting cell populations. Further experiments are in progress to investigate antigen-presenting functions of Facb-R+ cells using specific antigens. Our data on the functions of Facb-R+ cells are similar but not identical to those described for L cells by Lobo. These include inhibition of immunoglobulin synthesis following treatment with immune complexes and enhancing effects on lymphocyte proliferation. Further studies are required to determine whether, under certain circumstances, human Facb-R+ cells may be stimulated to exert a direct suppressive action, although some evidence for such an effect has recently been obtained in mice.

Results from the present study do indeed show similarities to those obtained in mice where Facb-R+ cells were unaffected by delayed hypersensitivity reactions to oxazolone or to sheep erythrocytes but were elevated during the secondary antibody response to the latter antigen. This report also demonstrated that antigen-specific Facb fragments could dramatically suppress specific antibody production in vivo and that Facb-R+ cells might therefore mediate IgG-dependent feedback inhibition of further antibody synthesis. Such feedback inhibition has been recognised for many years and has been considered to operate either via a direct blockade of B lymphocytes or by interfering with T-B cell interactions.
interactions.\textsuperscript{19} The present study clearly shows that, although PWM-dependent IgG synthesis is markedly inhibited by Facb-R\textsuperscript{*} cell depletion, mitogen-induced T cell proliferation is virtually unaffected. This suggests that Facb-R\textsuperscript{*} cells do not interact significantly with T lymphocytes, and, since Facb-R\textsuperscript{*} cells do not have any characteristics of B lymphocytes,\textsuperscript{1} our studies might be taken to support Hoffman’s concept of feedback inhibition of antibody production, namely, an effect on T-B cell co-operation.\textsuperscript{19}

Although the precise mechanism whereby Facb-R\textsuperscript{*} cells are involved in feedback inhibition remains to be elucidated, our results strongly suggest that rheumatoid PBMC are significantly less sensitive to such regulation than healthy cells. This might be due to the increased numbers of Facb-R\textsuperscript{*} cells in the rheumatoid samples. However, this increase is small (up to 5-fold) compared with the decreased sensitivity of RA cells to inhibition by Facb fragments (100-fold, Fig. 1). There is evidence that rheumatoid Facb-R\textsuperscript{*} cells are in an activated state when isolated ex vivo (in preparation) and thus could be less susceptible to the effects of ligands added in vitro. Alternatively, some rheumatoid B cells might be inherently resistant to feedback suppression by IgG antibody. Such a selective immunoregulatory defect affecting an autoimmune response would lead to excessive antibody production with the likelihood of serious consequences, including immune complex deposition and subsequent inflammatory tissue damage.

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