Natural Inhibitors of T-Cell Activation in Hodgkin’s Disease

By Matthias Roux, Burkhart Schraven, Albert Roux, Heinold Gamm, Roland Mertelsmann, and Stefan Meuer

Secondary immunodeficiency is frequently observed in Hodgkin’s disease (HD) and is due in part to impaired T-cell function. Using monoclonal antibodies that bind to triggering molecules of human T lymphocytes (CD3/Ti antigen receptor; CD2 E-rosette receptor) and exert functional effects on T-cell activation, we have investigated in vitro immune responses of circulating lymphocytes from patients with HD in progression (n = 9) and in remission (n = 14). In patients with progressive HD, a severe dysfunction of the alternative CD2-mediated T-cell activation pathway was detected (49.3 ± 14.2 vs. 9.4 ± 5.1 cpm × 10–3, in controls, P < .01; n = 9) that parallels the reduced capacity of T lymphocytes to form rosettes with sheep red blood cells. Diminished alternative pathway activation in HD is not only due to a defect at the cellular level but also due to soluble mediators in the patients’ plasma. Plasma from patients in progression markedly reduces CD2 mediated activation (P < .01). These activities interfere, at least in part, with CD2/CD58 interactions and, therefore, reduce T-lymphocyte triggering through this amplifier mechanism.

The analysis of discrete signals underlying the activation of human regulatory and effector T cells has been facilitated by the identification of cell surface receptors with monoclonal antibodies (MoAbs) and the availability of recombinant cytokines. Unlike before, when plant lectins had to be used to study cell triggering in vitro, a number of MoAbs exist that act in a ligand-like fashion on membrane receptors and stimulate T cells to express their functional programs. These reagents could also serve as potent tools in investigating the molecular basis of disorders of the immune response in humans.

Triggering of the CD3/Ti antigen receptor complex by MoAb initiates clonal expansion of antigen-specific effector cells. Additional signals can be mediated via the CD2 sheep erythrocyte receptor and can contribute to the amplification and acceleration of T-cell proliferation and mediator production. In this regard, interaction of CD2 with its widely distributed ligand, CD58 (formerly LFA3), delivers one potent triggering signal to T cells. In addition, CD58 participates in cytotoxic T cell/target cell interaction, in adhesion of T lymphocytes to thymic epithelium, and, probably, because CD58 is expressed on endothelial cells, in T-lymphocyte recirculation. Interference of CD2/CD58 interaction with MoAb blocks a number of T effector functions in vitro. It seems likely that diminished binding of CD2 to CD58 should be of functional importance to T-lymphocyte activation in vivo as well.

Human T cells bind to sheep red blood cells (SRBC) via the sheep homologue of the human CD58 molecule. A reduced capacity of rosette formation between sheep erythrocytes and T cells, as observed in a number of disorders of the human immune response, could serve as a “marker” for the existence of mechanisms that interfere with the CD2-mediated pathway of T-cell activation in vivo.

A reduced capacity of T lymphocytes of patients suffering from Hodgkin’s disease (HD) to form rosettes with sheep erythrocytes has been reported. These findings were initially ascribed, in part, to the relative lymphocytopenia in HD. However, it was also shown that unknown serum factors can mediate such an effect. The availability of MoAbs that selectively deliver activating signals through CD3/Ti or CD2, respectively, prompted us to investigate whether diminished E-rosette formation in HD is associated with deficiency of one or the other T-cell activation pathway.

MATERIALS AND METHODS

Patients. The 23 patients investigated suffered either from HD in progression (n = 9) or in remission (n = 14). Staging was performed according to the “Hodgkin’s Disease Staging Classification Committee” (Table 1). None of the patients received any therapy at the time of investigation. The control subjects (n = 9) were healthy members of the laboratory staff (age, 25 to 32 years, four women, five men).

Preparation of lymphocytes and plasma. Heparinized blood samples were spun for 20 minutes at 460g to separate plasma. Plasma was then heat-inactivated for 30 minutes at 56°C and then spun at 3,300g for 20 minutes to remove aggregates. The supernatant was stored at 5°C. The cell pellet was resuspended in RPMI 1640 (GIBCO, Paisely, Scotland), 2% L-glutamine (200 mmol/L; GIBCO), 1% penicillin-streptomycin (10,000 IU/mL penicillin, 10,000 μg/mL streptomycin; GIBCO), and peripheral blood mononuclear cells (PBMC) were separated by Ficoll-Hypaque (Pharma-cia, Uppsala, Sweden) density centrifugation. Subsequently, PBMC were dissolved in RPMI 1640, 2% L-glutamine, and 1% penicillin-streptomycin supplemented with 15% of the indicated plasma and kept at 37°C, 7% CO2, 100% humidity for 2 hours before the experiments.

Purified T cells were prepared as follows: PBMC from healthy donors were mixed with sheep erythrocytes (20 μL of a 5% vol/vol suspension/106 PBMC), spun at 73g for 5 minutes, and then incubated for 1 hour at room temperature. Subsequently, cells were gently resuspended, the suspension underlayered with Ficoll-Hypaque (Pharmacia), and spun for 20 minutes at 200g and for 15 minutes at 460g. Sheep erythrocytes bound to the pelleted rosetting T cells were then lysed with ACK solution (155 mmol/L NH4Cl, 10 mmol/L KHCO3, 0.1 mmol/L K-EDTA). Separated T cells were twice washed with RPMI 1640, 2% L-glutamine, 1% penicillin-streptomycin, and 5% human serum and incubated for 45 minutes.

Address reprint requests to Matthias Roux, MD, Deutsches Krebsforschungszentrum, Heidelberg; III. Med. Klinik, Johannes Gutenberg-Universität Mainz; and Med. Klinik und Poliklinik, Albert Ludwigs-Universität Freiburg, Germany.


From Abteilung Angewandte Immunologie, Deutsches Krebsforschungszentrum, Heidelberg; III. Med. Klinik, Johannes Gutenberg-Universität Mainz; and Med. Klinik und Poliklinik, Albert Ludwigs-Universität Freiburg, Germany.

The publication costs of this article were defrayed in part by page charge payment. This article must therefore be hereby marked "advertisement" in accordance with 18 U.S.C. section 1734 solely to indicate this fact.

© 1991 by The American Society of Hematology.


2365
at 37°C with 100 μL MoAb aHLA II, 100 μL MoAb MO1, and rabbit complement to lyse preactivated T cells and residual monocytes. Cells were then washed twice again before use. This procedure to prepare purified T cells does not influence CD2- or CD3-mediated activation, provided that the SRBC are properly lysed.

Rosetting tests. Thirty microliters of sheep erythrocytes (5% [vol/vol] in RPMI 1640) were added to 10^6 PBMC that had been preincubated for 2 hours in RPMI, 2% L-glutamine, 1% penicillin-streptomycin, and 15% of the indicated plasma at 37°C. Cells were spun at 600 rpm for 5 minutes and to form rosettes at room temperature for 1 hour. Afterwards, the pellet was gently resuspended. Rosetting and nonrosetting cells were separated by Ficoll-Hypaque density centrifugation and counted.

MoAbs and mitogens: MoAbs were used in ascites form in predetermined concentrations: CD4 (AICD4.1), CD8 (AICD8.2), α T111α (AICD2.1.1A), α T11,α (AICD2.2.1B). CD3 MoAb (R28C8), α T11, (1OLOD4Cl), and α T11, (IMON02A6) were kindly provided by Drs Schlossmann and Reinherz (Dana-Faber Cancer Institute, Boston, MA). aHLA II (No. 6) and αCD58^+ (G 26.1) were provided by Dr T. Hänig (Würzburg, Germany).

Purified CD3 MoAb (OKT3; American Type Culture Collection, Rockville, MD) purified by high-performance liquid chromatography from mouse ascites was covalently coupled to cyanogen bromide (CNBr)-activated Sepharose protein A beads (Pharmacia) at a concentration of 5 mg/mL swelled beads according to the instruction of the supplier. The beads were stored in phosphate-buffered saline (PBS)/0.1% NaN₃ (vol/vol) and extensively washed before use in the proliferation studies.

Phytohemagglutinin (PHA) was purchased from Wellcome (Burgwedel, Germany) and used at a final concentration of 0.1 μg/mL.

Natural interleukin-2 (nIL-2) is a highly purified preparation of human IL-2 (Biotech, Dreieich, Germany).

Recombinant human IL-4 purified from _Escherichia coli_ was a generous gift of Dr J. de Vries (Laboratoire Unicet, Dardilly, France).

The concentrations at which stimuli (PHA, CD3 MoAb-Sepharose beads, αT11, + αT11, and αT11,α) were used were previously established on PBMC of healthy donors.

**Immunofluorescence.** Single-color fluorescence flow cytometric analyses were performed on an EPICS 752 cell sorter (Coulter Electronics, Hialeah, FL). Cells (1 × 10^6) were stained for 30 minutes at 4°C with saturating concentrations of MoAb and washed twice with PBS (Seromed, Berlin, Germany), followed by incubation with 50 μL of a 1:60 dilution of goat antimouse fluorescein isothiocyanate-conjugated antibody (Coulter Electronics). Cells were fixed in 0.5 mL PBS/1% (vol/vol) paraformaldehyde. Ten thousand cells were analyzed per sample.

**Proliferative assays.** PBMC or purified T cells (1 × 10^6), respectively, were cultured in round-bottomed microtiter plates (Costar, Cambridge, MA) in 200 μL RPMI 1640 supplemented with 2% L-glutamine, 1% penicillin-streptomycin, and 15% of plasma as indicated. After 72 hours, individual wells were pulsed with 57 kBq /μL-thymidine (185 gBq/mmol; Amersham, Braunschweig, Germany) for 18 hours and harvested using an Inotec cell harvester (Wohlen, Switzerland). H-thymidine incorporation was measured using a liquid scintillation spectrometer (Beckmann, Munich, Germany). Results are expressed as means of triplicates ± SEM. Values of the proliferation assays and the rosetting tests were transformed to logs and compared by t-test analysis.

### Results

**Rosette-forming assay.** PBMC from control subjects form rosettes with sheep erythrocytes at 62% ± 11% when incubated in autologous plasma before the test. For reasons of better comparability, this control value was set at 100% and the respective values of the patients expressed as percentage of the control. The capacity of PB lymphocytes from HD patients in remission to bind to sheep erythrocytes is 97% ± 9.2% as compared with healthy controls (P < .05). In contrast, rosette formation of PBMC from patients with active disease was reduced to 76% ± 6.2% when compared with the control cells (P < .01), confirming data previously described by other investigators.16-20

**Immunofluorescence.** To investigate whether the reduced capacity of PBMC from HD patients was due to reduced expression of cell surface molecules known to be involved in T-cell activation and SRBC-rosette formation we performed immunofluorescence studies. To this end, 5 × 10^6 cells/sample were labeled with MoAbs directed against the indicated surface molecules (Table 2) and 10^6 cells/sample were analyzed on a flow cytometer.

As shown in Table 2, both groups of patients had slightly reduced numbers of circulating T cells as shown by the diminished count of CD3^+ PBMC. The CD2 epitopes critical for CD2/CD58 interaction (ie, T11,α and T11,α) are expressed. Although not confirmed by dual-fluorescence labeling, this analysis suggests that CD3^+ T cells also bear CD2. In addition, the density of CD2 molecules and/or epitopes on the T-cell surface was not diminished in patients, as calculated from mean channel fluorescence values (data not shown).

**Proliferative assays.** To investigate the functional capacity of T cells from HD patients to respond to triggering via the TCR, a Sepharose-linked CD3 MoAb (seph-CD3) was used at a final concentration of 0.1 pg/mL. Before use in the proliferation studies.
T-cell activation in Hodgkin's disease

MoAb binding to T-cell surface molecules as determined by an EPICS 752 cell sorter (percent positives ± SEM). PBMC of the individual subjects were prepared, incubated with the indicated MoAb, and stained with a goat antimouse fluorescein isothiocyanate-conjugated second antibody as described in Materials and Methods. The negative controls were always less than 3%.

Table 2. Immunofluorescence of T-Cell Surface Molecules

<table>
<thead>
<tr>
<th></th>
<th>Control Subjects</th>
<th>Patients in Remission</th>
<th>Patients in Progression</th>
</tr>
</thead>
<tbody>
<tr>
<td>CD3</td>
<td>68 ± 5.3</td>
<td>46 ± 4.3</td>
<td>52 ± 7.8</td>
</tr>
<tr>
<td>CD4</td>
<td>47 ± 3.6</td>
<td>32 ± 4.8</td>
<td>32 ± 5.4</td>
</tr>
<tr>
<td>CD8</td>
<td>25 ± 2.1</td>
<td>24 ± 2.3</td>
<td>23 ± 4.9</td>
</tr>
<tr>
<td>Ratio CD4/CD8</td>
<td>2.0 ± 0.2</td>
<td>1.4 ± 0.2</td>
<td>1.8 ± 0.5</td>
</tr>
<tr>
<td>CD2.1A</td>
<td>82 ± 4.8</td>
<td>59 ± 5.2</td>
<td>57 ± 10.9</td>
</tr>
<tr>
<td>CD2.1B</td>
<td>78 ± 3.3</td>
<td>57 ± 4.2</td>
<td>62 ± 8.4</td>
</tr>
<tr>
<td>CD2.2</td>
<td>76 ± 3.7</td>
<td>58 ± 6.0</td>
<td>61 ± 8.6</td>
</tr>
<tr>
<td>CD2.3</td>
<td>14 ± 2.2</td>
<td>28 ± 3.3</td>
<td>16 ± 5.3</td>
</tr>
<tr>
<td>CD58</td>
<td>11 ± 4.6</td>
<td>18 ± 2.1</td>
<td>7 ± 5.4</td>
</tr>
<tr>
<td>HLA II</td>
<td>8 ± 1.5</td>
<td>17 ± 1.9</td>
<td>15 ± 3.6</td>
</tr>
</tbody>
</table>

used. As shown in Fig 1A, both control lymphocytes and cells from patients in remission proliferated to a similar extent (15.5 ± 3.3 cpm x 10^3 in controls vs 19.5 ± 4.8 cpm x 10^3, ie, 125% of control; P > .05), whereas PBMC from the majority of patients with active HD showed a slightly poorer response (8.8 ± 2.0 cpm x 10^3, ie, 57% of control; P > .05).

T-cell triggering via the CD2-dependent pathway of T-cell activation by MoAbs aT11, and aT11, resulted in incorporation of 49.3 ± 14.2 cpm x 10^3 in normal PBMC (Fig 1B). In contrast, cells from HD patients in remission responded in a reduced fashion (23.0 ± 5.8 cpm x 10^3, ie, 47% of control; P < .05). Under the same conditions, lymphocyte proliferation from patients in progression was strongly inhibited (9.4 ± 5.1 cpm x 10^3, ie, 19% of control; P < .01).

Figure 1C shows that 3H-thymidine incorporation was also reduced when PHA (0.1 μg/mL) was used for stimulation. Thus, control PBMC incorporated 71.3 ± 17.1 cpm x 10^3 3H-thymidine. In contrast, under identical experimental conditions, PBMC from HD patients in remission or in progression showed a diminished proliferation (35.9 ± 8.4 cpm x 10^3, ie, 50% of control; P < .05; and 20.9 ± 6.6 cpm x 10^3, ie, 29% of control, respectively; P < .007). The correlation between the response after CD2 stimulation with PHA-mediated activation is not surprising because the CD2 pathway of activation is critically involved in the action of PHA.22

The low T-cell responses after CD2 triggering in patients with active disease could be partially restored by addition of MoAb aT11, which mimics the signal mediated to T cells by the CD58 molecule (Fig 1D).23 Under these conditions, reduction of proliferation was markedly improved (19% of control to 56% in patients with progressive disease [P < .001] and 47% of control to 81% in patients in remission [P < .001], respectively).

To determine whether the deficiency in T-lymphocyte activation was due to a defect at the cellular level or due to factors present in the patients' plasma, we performed proliferation assays with T lymphocytes from a healthy subject and plasma either from a second healthy donor or from patients with progressive HD. As shown in Fig 2, when compared with plasma from a healthy donor, plasma from HD patients reduced proliferation of PBMC from healthy individuals to a similar degree in the stimulation systems used as previously observed with PBMC of HD patients. Note that T-cell triggering via CD3 resulted in a lower 3H-thymidine incorporation than stimulation via CD2 and should therefore be more susceptible to blocking influences. Nevertheless, triggering by MoAb T11, + T11, was reduced by 80% (P < .01), whereas CD3 triggering was only slightly diminished (P > .05). Again, this predominant inhibition of CD2-mediated T-cell proliferation could be partially circumvented in the presence of αT11, MoAb (59% of control; P < .05) (Fig 2).

Activation of T cells by seph-CD3 MoAbs requires the presence of monocytes to induce IL-2 production. In contrast, IL-2 responsiveness (ie, IL-2 receptor expression) can be induced after seph-CD3 triggering even in the absence of monocytes.24-26 Therefore, it is likely that, in addition to signals mediated via the CD3-Ti antigen receptor, the CD3 system may also contain activation stimuli delivered through CD2/CD58 expressed on the proportion of activated T cells and monocytes contained in PBMC, respectively. It follows that the inhibitory effect on T-cell activation by seph-CD3, observed above by plasma from HD patients, could have been due to interference with CD2/CD58 binding and not with the signals transmitted through the T-cell receptor itself. To investigate this point, we established a modified CD3-triggered proliferation system in which signals delivered via the CD2 molecule were excluded. To this end, resting T cells were vigorously purified. As a control of proper purification, T-cell proliferation must not be induced by either CD3, PHA, or IL-2 alone, as shown by others. T cells were activated by seph-CD3 MoAb plus IL-2 in the presence of a MoAb directed at the T11, epitope (MoAb AICD2.2.1B) (Fig 3). This antibody selectively inhibits binding of CD58 to CD2 without providing a functional signal. In line with the above considerations, blocking of CD2/CD58 binding by MoAb AICD2.2.1B abrogated the activation by seph-CD3 plus IL-2 to a substantial degree. Nevertheless, plasma from HD patients still reduces the residual proliferation by greater than 50%. Note that this inhibition could be circumvented neither by the addition of IL-2 or IL-4 (Fig 3).

Discussion

Besides triggering through the CD3-Ti antigen receptor complex, T lymphocytes can be activated by MoAbs directed at the SRBC receptor now termed CD2.1,2 The physiologic ligand of CD2, CD58, has been identified.8,28 The interaction between CD2 and CD58 has been shown to be essential for optimal antigen receptor-mediated signaling.8,28 Moreover, it has been shown that binding of CD2 to CD58 delivers a triggering signal to T cells, which leads to polyclonal T-lymphocyte activation in combination with antibodies directed at distinct epitopes of CD2.24 Moreover, blockade of CD2/CD58 binding inhibits T-cell activation in a number of immunologic processes, eg, mixed
lymphocyte reaction and antigen-driven proliferation. This finding suggests that CD2/CD58 interactions are involved in physiologically occurring immune responses. Formation of rosettes between T cells and SRBC mimics CD2/CD58 binding because this reaction is mediated mainly through CD2 expressed on T lymphocytes and T11 Ts, the sheep homologue of CD58 on SRBC. In HD, a reduced E-rosette-forming capacity of T cells has been well documented. Given the in vitro functional importance of CD2/CD58 interaction for the generation of specific immune responses, a defect of T-cell activation might exist at this level in vivo as well. This defect could be responsible in part for the severe immunodeficiency existing in HD.

In this report we show that the diminished E-rosette formation in patients with active HD results in a nearly abolished capacity of T cells to respond to CD2 triggering. This effect is obviously not due to a primary defect at the cellular level but rather is related to inhibitory activities in the plasma from HD patients, because the expression of CD2 on T cells of HD patients is hardly altered. This view is further supported by experiments (Figs 2 and 3) in which an MoAb directed at one CD58 binding site on CD2 partially restores the capacity of lymphocytes from HD patients to proliferate to CD2-dependent stimuli. It seems possible that due to its high binding affinity this antibody (αT11.1) outcompetes circulating blocking factors in HD plasma that might have bound to the CD2 molecule of patient T cells. Whether these “factors” in the patients'
plasma are tumor cell products or, alternatively, physiologic activities induced in the course of the disease process is not known at present. It is not unlikely that a soluble form of one of the ligands involved in CD2/CD58 interaction exists in the sera of patients with HD. Besides a transmembrane form of CD58, a phosphatidylinositol (PI)-anchored form of this molecule could be identified. This finding makes it likely to be released from the cell surface by specific phospholipases, as could be shown in vitro. We are now establishing an enzyme-linked immunosorbent assay (ELISA) system to determine whether soluble forms of CD58 and CD2 exist.

Besides CD2-mediated activation, T-cell triggering via the antigen receptor was also partially inhibited. This result was shown in a system in which the proportion of CD3-driven activation that likely depends on the interaction between CD2 and CD58 was essentially diminished. This finding suggests that, besides factors that interfere with CD2/CD58 binding, inhibitors of T-cell proliferation are present in the HD patients' plasma that affect T-cell acti-

Fig 2. Influence of HD patients' plasma on the MoAb response of PBMC from a healthy donor. PBMC (1 × 10⁶/microculture well) were incubated in separate experiments in RPMI 1640 culture medium supplemented either with (∆) 15% plasma of healthy control persons (n = 9) or (○) plasma of HD patients in progression (n = 9). Proliferation was determined by [H]-thymidine incorporation as described (mean ± SEM).

Fig 3. Purified T cells of a healthy donor (1 × 10⁶/well) were incubated with the indicated plasma and stimulated with the MoAb as described in Materials and Methods. Proliferation was determined by [H]-thymidine incorporation. To test for influences of the plasma preparation, a heat-inactivated control serum of a healthy donor was included in this test.
viation through CD3 at a distinct level. The finding that these inhibitory activities cannot be circumvented by the lymphokines IL-2 and IL-4 suggests a defect in the signalling process required for antigen receptor-mediated stimulation.

In conclusion, this study indicates that reduced E-rosette formation of T cells in HD represents a marker for diminished T-lymphocyte activation via the CD3-mediated "alternative pathway." Thus, this study presents for the first time evidence that defects in amplifier mechanisms, such as CD2 triggering of T-cell activation, may contribute to the development of secondary immunodeficiencies in vivo. It is tempting to speculate that this finding could be of potential clinical significance in other diseases in which reduced E-rosette formation has been described as well.34,35

REFERENCES

29. Peterson A, Seed B: Monoclonal antibody and ligand binding sites of the T cell erythrocyte receptor (CD2). Nature 329:842, 1987


Natural inhibitors of T-cell activation in Hodgkin's disease

M Roux, B Schraven, A Roux, H Gamm, R Mertelsmann and S Meuer