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### Research Article

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# Surface Markers of Complement Receptor Lymphocytes

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**ABSTRACT** Normal blood lymphocytes bearing complement receptors (CRL) were divided into two populations, one expressing both CR<sub>1</sub> (C4b-C3b receptor) and CR<sub>2</sub> (C3d receptor) and a second expressing only CR<sub>1</sub>. Nearly all of the population that expressed both CR<sub>1</sub> and CR<sub>2</sub> also bore membrane surface immunoglobulins (Ig) and Ia antigens. The majority of cells that had only CR<sub>1</sub> lacked detectable surface Ig. These Ig<sup>-</sup> CR<sub>1</sub><sup>+</sup> CR<sub>2</sub><sup>-</sup> cells could be distinguished from the majority of monocytes and immature granulocytes, in that the latter ingested latex particles and expressed CR<sub>2</sub> as well as CR<sub>1</sub>. The Ig<sup>-</sup> CR<sub>1</sub><sup>+</sup> cells were further subdivided into an Ia-bearing subpopulation and another that lacked Ia. Among the Ig<sup>-</sup> Ia<sup>-</sup> CR<sub>1</sub><sup>+</sup> cells, one third formed spontaneous rosettes with sheep erythrocytes while all of the remaining CRL were erythrocyte-rosette negative. Essentially all CRL in normal blood had IgG Fc receptors, but a qualitative heterogeneity in the Fc receptors of Ia<sup>+</sup> CRL vs. Ia<sup>-</sup> CRL was observed in their binding of different immune complex systems.

## INTRODUCTION

In several previous studies of complement receptor lymphocytes (CRL)<sup>1</sup> the dominant finding has been that

these cells are heterogeneous in their expression of different types of membrane markers (1-5). Whereas most laboratories were in agreement that the CRL had surface immunoglobulin (Ig) and Fc receptors (FcR), some CRL did not have detectable surface Ig (2, 4, 5), and a minor proportion of CRL formed erythrocyte (E) rosettes (6). Thus, there was some question as to whether complement (C) receptor expression was restricted to the bone marrow-derived lymphocyte (B-cell) lineage. Because in the past the only reliable criteria for the identification of human B cells was the demonstration of membrane Ig determinants, the whole question of Ig<sup>-</sup> CRL was revived when it was shown that the usual techniques for measurement of surface Ig could lead to an overestimation of the proportion of Ig-bearing cells because anti-Ig reagents occasionally bound to FcR<sup>+</sup> Ig<sup>-</sup> cells (7). Recently, human Ia antigens have been shown to be B-cell-specific markers of considerable utility (8), and simultaneous analysis of Ig and Ia antigens has led to the demonstration of Ig<sup>-</sup> Ia<sup>+</sup> B cells (9, 10). Thus, the possibility arose that CRL which lack demonstrable Ig could be B cells if they expressed Ia antigens. Finally, any complete characterization of the CRL population should include the distinction of CRL which express either one or the other of two distinct types of C receptors. Although the majority of CRL contain both types of C receptors, some normal peripheral blood lymphocytes express only CR<sub>1</sub> (C4b-C3b receptor), whereas some other normal tonsil lymphocytes express only CR<sub>2</sub> (C3d receptor) (4, 5).

The present study was instituted to analytically evaluate the surface markers of the CRL by utilizing a combination of all of these advances in methodology. Normal blood CRL were found to be heterogeneous in their content of CR<sub>1</sub>, CR<sub>2</sub>, surface Ig, Ia antigens, and FcR. The majority of CRL expressed B-cell-specific surface Ig and (or) Ia determinants, whereas

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<sup>1</sup> Abbreviations used in this paper: C, complement; CR<sub>1</sub>, complement receptor type one, the immune adherence (C4b-C3b) receptor; CR<sub>2</sub>, complement receptor type two, the C3d receptor; CRL, complement receptor lymphocytes; E, erythrocyte; EAC, sheep erythrocyte-rabbit IgM antibody-complement complex; E rosette, spontaneous sheep erythrocyte rosette (1); FcR, Fc receptors; FITC, fluorescein isothiocyanate; Ia antigens, human B cell-specific analogues of murine

lymphocyte antigens encoded by I-region genes; KLH, keyhole limpet hemocyanin; OVA, ovalbumin; TRITC, tetramethylrhodamine isothiocyanate.

a small proportion of CRL lacked both Ig and Ia antigens; included among these were a minor proportion of CRL that formed E-rosettes.

## METHODS

**Isolation of mononuclear cells and identification of lymphocytes.** Mononuclear cell fractions were obtained by density centrifugation (400 *g*, for 45 min at 20°C) from whole or dextran-sedimented, heparinized normal blood, at the density interface formed with  $d = 1.078$  g/ml Ficoll-Hypaque (Ficoll, Pharmacia Fine Chemicals Inc., Piscataway, N. J., Hypaque, Winthrop Laboratories, New York) (11, 12). After two washes with phosphate-buffered saline (PBS), the cells were resuspended in Hanks' balanced salt solution and incubated with 1.1  $\mu$ m latex particles for 1 h at 37°C (12). After removal of free latex particles by three washes with warm PBS at 400 *g* for 10 min, the cells were resuspended in PBS that contained 1% bovine serum albumin and 0.2% NaN<sub>3</sub> and examined for the extent of latex ingestion by phagocytic cells. For this purpose, air-drained cell smears were stained for peroxidase containing cells (13), followed by staining with Wright-Giemsa. From 10 to 35% of mononuclear cells ingested latex and this included an average of 95% of the monocytes and granulocytes simultaneously identified by peroxidase and Wright-Giemsa staining. Thus, 97–99% of the latex ingestion-negative cells were lymphocytes.

**Assay for CR<sub>1</sub> and CR<sub>2</sub>-bearing cells.** CR<sub>1</sub> and CR<sub>2</sub> were detected as previously described by rosette formation with sheep erythrocyte-rabbit IgM antibody-complement complexes (EAC): EAC14b, EAC1-3b, and EAC1-3d prepared with purified human C components (14).

**Preparation of fluorochrome-conjugated anti-Ig.** Rabbit antisera specific for immunoglobulin  $\mu$ -,  $\delta$ -,  $\alpha$ -, and  $\gamma$ -heavy chains and  $\kappa$ - and  $\lambda$ -light chains were prepared and appropriately absorbed on solid phase immunoabsorbents. After isolation of IgG antibody from each antiserum by DEAE cellulose chromatography (12), each anti-Ig type was divided into two parts, one that was treated with pepsin (Worthington Biochemical Corp., Freehold, N. J.) to produce F(ab')<sub>2</sub> fragments (15), and the other that was retained as whole IgG. The minimum amount of pepsin required for complete cleavage of all IgG was separately determined with each antibody by pilot studies analyzed by electrophoresis in sodium dodecyl sulfate-polyacrylamide gels. In some instances, the duration that the isolated IgG was stored before digestion and the particular preparation of pepsin necessitated adjustment of the time and concentration of pepsin used for digestion. F(ab')<sub>2</sub> fragments were separated from trace amounts of uncleaved IgG and from pFc fragments by gel filtration on a 5  $\times$  150-cm column of either Sephacryl S-200 or Sephadex G-150 (Pharmacia Fine Chemicals Inc.) equilibrated with 0.05 M Tris citrate buffer pH 8.0 that contained 1.0 M NaCl. The F(ab')<sub>2</sub> fragments were shown to be free of uncleaved IgG and pFc fragments by sodium dodecyl sulfate-polyacrylamide gel electrophoresis and by immunodiffusion analysis with goat anti-rabbit Fc fragment specific serum. Any trace amounts of uncleaved IgG antibody were removed by absorption with Protein A-Sepharose (Pharmacia Fine Chemicals Inc.). Both the whole IgG and F(ab')<sub>2</sub>-anti-Ig were conjugated to tetramethylrhodamine isothiocyanate (TRITC), and conjugate fractions eluting from DE-52 Cellulose (Whatman, Inc., Clifton, N. J.) columns with 0.05–0.125 M NaCl in 0.01 M sodium phosphate pH 7.5 were used to stain cells (16, 17). Each TRITC-anti-Ig conjugate was tested for both specificity and potency in fluorescence staining of lymphoid cell lines. Additional absorptions were

made according to the analyses of the patterns of fluorescence staining obtained with either various established lymphoblastoid cell lines or chronic lymphatic leukemic lymphocytes known to contain only one particular heavy chain class and light chain type. In subsequent tests with normal lymphocytes, the anti-Ig reagent was used at a two to fourfold higher concentration than that which gave the maximum number and fluorescence intensity of stained cells.

**Immunofluorescence assay for surface Ig, FcR, and Ia antigens.** Direct immunofluorescence staining of surface Ig was performed with either the whole IgG or F(ab')<sub>2</sub>-anti-Ig TRITC conjugate as previously described (12, 17). FcR were detected by fluorescence assay with soluble fluorochrome-conjugated immune complexes prepared at antibody excess (12, 18). Ia antigens were fluorescence stained with a rabbit F(ab')<sub>2</sub> anti-Ia-fluorescein isothiocyanate (FITC) (or TRITC) conjugate, prepared and tested as described previously (9).

**Spontaneous sheep erythrocyte rosettes (E-rosettes), thymus-derived lymphocyte (T-cell)-enriched, and T-cell-depleted fractions.** E-rosettes were formed with either neuraminidase-treated sheep E (19) or with untreated E in the presence of heat-inactivated human AB serum at 4°C (20). T-cell-enriched and T-cell-depleted fractions were prepared from mononuclear cell fractions by separation of E-rosettes on Ficoll-Hypaque gradients (20). E-rosette depleted fractions contained <2% E-rosettes, 50% latex-positive monocytes, and 30–40% Ia-positive lymphocytes. T-cell fractions prepared from the E-rosette pellet fractions by lysis of sheep E (20), contained 98–99% E-rosette-forming cells and only 0.5–1.0% of cells that expressed Ia determinants.

**Double and triple marker assays.** Cells were stained simultaneously with a TRITC-conjugated reagent specific for either Ig, Ia antigens or FcR, and (or) an FITC-conjugated reagent specific for either Ia antigens or FcR, and then mixed with EAC to form C receptor-dependent rosettes. All possible combinations of one, two, or three different markers on individual cells were separately enumerated by sequential examination of each microscopic field with blue light fluorescence (FITC), green light fluorescence (TRITC), and visible light phase contrast optics (rosettes).

## RESULTS

**C Receptor type of normal blood CRL.** When the normal blood lymphocytes from 21 normal individuals were tested for EAC rosette formation, an average of 17.0% of lymphocytes formed rosettes with either EAC14b (CR<sub>1</sub> specific) or EAC1-3b, whereas only 9.7% of lymphocytes formed rosettes with EAC1-3d (CR<sub>2</sub> specific). Because in each individual a mixture of EAC14b and EAC1-3d did not yield more rosetted lymphocytes than did EAC14b alone, CR<sub>2</sub>-bearing cells were concluded to be a subpopulation of CR<sub>1</sub>-bearing cells. Normal blood thus contained two populations of CRL, 9.7% CR<sub>1</sub><sup>+</sup> CR<sub>2</sub><sup>+</sup> cells, and 7.3% CR<sub>1</sub><sup>+</sup> CR<sub>2</sub><sup>−</sup> cells, representing a combined total of 17.0% CRL. Because all normal blood CRL contained CR<sub>1</sub>, the total number of CRL could be determined by rosette formation with either EAC14b or EAC1-3b.

**Expression of surface Ig and Ia determinants on CRL.** Normal lymphocytes from 21 individuals were stained with either whole IgG anti-Ig or F(ab')<sub>2</sub> anti-Ig specific for all heavy chain classes and light chain types,

and then the stained lymphocytes were assayed for EAC rosette formation (Table I). Whole IgG-anti-Ig and the F(ab')<sub>2</sub> derivative detected similar proportions of Ig<sup>+</sup> CR<sup>+</sup> and Ig<sup>-</sup> CR<sup>+</sup> cells. However, the whole IgG-anti-Ig detected significantly more Ig<sup>+</sup> CR<sup>-</sup> cells than did the F(ab')<sub>2</sub> anti-Ig. Studies with heavy chain class-specific antibodies demonstrated that in most cases, nearly the same proportion of these Ig<sup>+</sup> CR<sup>-</sup> cells were detected with whole IgG-anti-γ as with the whole IgG polyvalent reagent, and that F(ab')<sub>2</sub> anti-γ stained only rare (<0.2%) CR<sup>-</sup> cells. However, it was also observed that in 15% of the normal individuals examined, whole IgG-anti-μ, δ detected 10–50% more Ig<sup>+</sup> cells than did the F(ab')<sub>2</sub>-anti-μ, δ derivative. The F(ab')<sub>2</sub> anti-Ig, rather than the whole IgG anti-Ig, was used in all subsequent assays for surface Ig.

Surface Ig was detected on nearly all CR<sub>2</sub>-bearing cells, however 2.0% of cells expressed Ig and lacked CR<sub>2</sub> and 0.3% expressed Ig and lacked CR<sub>1</sub> (Ig<sup>+</sup>, CR<sup>-</sup>, Table I). By contrast, one third of CR<sub>1</sub>-bearing cells lacked surface Ig (5.7% Ig<sup>-</sup> CR<sup>+</sup>). Thus, among the two normal blood CRL populations, most of the CR<sub>1</sub><sup>+</sup> CR<sub>2</sub><sup>+</sup> cells contained surface Ig (9.4% Ig<sup>+</sup> vs. 0.5% Ig<sup>-</sup>), whereas most of the CR<sub>1</sub><sup>+</sup> CR<sub>2</sub><sup>-</sup> cells lacked surface Ig (11.3% – 9.4% = 1.9% Ig<sup>+</sup> vs. 5.7% Ig<sup>-</sup>). To characterize further the Ig<sup>-</sup> CR<sub>1</sub><sup>+</sup> cells, CR<sub>1</sub>-bearing cells were examined simultaneously for surface Ig and Ia antigens by triple-marker assay (Table II). All Ig<sup>+</sup> CR<sub>1</sub><sup>+</sup> cells contained Ia antigens (11.2% of cells from 8 individuals), whereas less than half of the Ig<sup>-</sup> CR<sub>1</sub><sup>+</sup> cells contained Ia antigens (Ia<sup>+</sup> cells, 2.4%). The remaining Ig<sup>-</sup> CR<sub>1</sub><sup>+</sup> cells lacked detectable Ia determinants (Ia<sup>-</sup> cells, 3.2%). In all individuals examined, an average of 1.6% of cells bore Ia determinants but lacked both CR<sub>1</sub> and Ig determinants. In phase contrast microscopy, these Ia<sup>+</sup> cells were predominantly medium to large sized mononuclear cells with little or no visible cytoplasm and a smooth outer membrane.

TABLE I

Combined Assay of Normal Blood Lymphocytes for Surface Ig and C Receptors (CR)

| Reagents used                     | Receptor combinations detected  |                                 |                                 |
|-----------------------------------|---------------------------------|---------------------------------|---------------------------------|
|                                   | Ig <sup>+</sup> CR <sup>+</sup> | Ig <sup>+</sup> CR <sup>-</sup> | Ig <sup>-</sup> CR <sup>+</sup> |
|                                   | %                               |                                 |                                 |
| Whole IgG-anti-Ig* plus           |                                 |                                 |                                 |
| EAC1-3b (CR <sub>1</sub> )        | 11.7†                           | 2.2                             | 5.3                             |
| EAC1-3d (CR <sub>2</sub> )        | 9.2                             | 4.6                             | 0.3                             |
| F(ab') <sub>2</sub> anti-Ig* plus |                                 |                                 |                                 |
| EAC1-3b (CR <sub>1</sub> )        | 11.3†                           | 0.3                             | 5.7                             |
| EAC1-3d (CR <sub>2</sub> )        | 9.4                             | 2.0                             | 0.5                             |

\* Polyvalent, specific for μ-, δ-, γ-, α-, κ-, and λ-determinants.

† Averages from assay of 21 normal individuals.

TABLE II  
Heterogeneity of Ia Expression on Ig-Negative CRL as Compared to Ig-Positive CRL

|  | Ia <sup>+</sup> | Ia <sup>-</sup> |
|--|-----------------|-----------------|
|  | %               |                 |
| Ig <sup>-</sup> CR <sub>1</sub> <sup>+</sup> | 2.4*            | 3.2             |
| Ig <sup>+</sup> CR <sub>1</sub> <sup>+</sup> | 11.2            | 0               |

\* Averages from assay of eight normal individuals.

#### Exclusion of monocytes and immature granulocytes.

The majority of nonlymphoid cells ingested latex particles and were thus readily identified and excluded from surface marker determinations. Also, large cells with either an uneven outer membrane or a granular cytoplasm were excluded from surface marker counts regardless of whether or not they ingested latex. However, because some rare peroxidase-positive latex-negative cells were smaller than typical monocytes and contained few granules, additional tests were performed to determine if some of the Ig<sup>-</sup> CR<sub>1</sub><sup>+</sup> cells were nonlymphoid cells. Simultaneous Wright-Giemsa and peroxidase staining of EAC rosettes revealed that nearly all peroxidase-positive, latex-negative cells were CR<sub>2</sub><sup>+</sup>, and in this way differed from Ig<sup>-</sup> CR<sub>1</sub><sup>+</sup> lymphocytes that were CR<sub>2</sub><sup>-</sup> (Table I). In addition, it was found that depletion of adherent cells on plastic Petri dishes (5) had no effect on the proportions of Ig<sup>-</sup> CR<sub>1</sub><sup>+</sup> lymphoid cells.

**Heterogeneity of FcR on CRL.** Soluble FITC-labeled immune complexes were formed with a variety of different antigen-antibody systems. At antibody concentrations of 1–3 mg/ml, bright staining of 12–15% of blood lymphocytes was obtained with each of the different immune complex systems. Despite their producing nearly equivalent proportions of stained cells, it was also observed that two of these immune complex systems stained CRL while two other systems predominantly stained non-CRL. It was necessary to use a mixture of two of these systems to detect FcR on both CRL and non-CRL simultaneously. Of the two systems that bound to CRL, sheep anti-IgA and IgA was preferable to sheep anti-rabbit IgG F(ab')<sub>2</sub> and rabbit IgG F(ab')<sub>2</sub> because of the possible interference with other rabbit antibodies used in other simultaneous marker assays. Because no other immune complexes were available that had this selective affinity for CRL, certain additional controls were performed to assure that the sheep anti-IgA system was specific for FcR. First, parallel assay of each lymphocyte preparation with uncomplexed anti-IgA alone stained only 0.3% of cells, confirming that the assay was not detecting a large proportion of cells bearing surface IgA. Second, no fluorescence staining was observed when immune complexes were prepared with the IgA antigen plus

F(ab')<sub>2</sub> anti-IgA rather than intact IgA antibody. Thus, the assay was specific for cells bearing receptors for Fc contained in immune complexes.

Examination of FITC-immune complex-stained cells for EAC1-3b rosette formation revealed that while the sheep anti-IgA complexes primarily stained CR<sub>1</sub><sup>+</sup> cells, complexes formed with either rabbit anti-ovalbumin (OVA) and OVA or rabbit anti-keyhole limpet hemocyanin (KLH) and KLH primarily stained CR<sub>1</sub><sup>-</sup> cells. The absence of staining on CR<sub>1</sub><sup>+</sup> cells was most pronounced with the anti-OVA-OVA complexes, and on some occasions, KLH complexes stained some CR<sub>1</sub><sup>+</sup> cells in addition to CR<sub>1</sub><sup>-</sup> cells. However, when this was observed, the brightest fluorescence staining with these KLH complexes was on CR<sub>1</sub><sup>-</sup> cells, and the staining of CR<sub>1</sub><sup>+</sup> cells was noticeably weaker.

Either FITC-sheep anti-IgA-IgA or rabbit anti-OVA-OVA immune complexes or a mixture of these two types of complexes was used to label FcR in combination with TRITC-F(ab')<sub>2</sub>-anti-Ia and EAC1-3b for simultaneous assay of Ia antigens and CR<sub>1</sub> (Table III). With anti-OVA-OVA complexes, the majority of cells labeled were Ia<sup>-</sup> CR<sub>1</sub><sup>-</sup> (11.7%). Among the CR<sub>1</sub><sup>+</sup> cells, nearly all of the Ia<sup>-</sup> CR<sub>1</sub><sup>+</sup> cells were stained (3.2%), whereas only a small proportion of Ia<sup>+</sup> CR<sub>1</sub><sup>+</sup> cells were stained (1.2%). Anti-IgA-IgA complexes differed from the anti-OVA-OVA complexes in that they predominantly labeled Ia<sup>+</sup> CR<sub>1</sub><sup>+</sup> cells (13.4%) and bound to few Ia<sup>-</sup> CR<sub>1</sub><sup>-</sup> cells (0.4%).

The heterogeneity of immune complex binding to different cell populations was further revealed when cells were simultaneously stained with the anti-IgA complexes plus the anti-OVA complexes (Table III). FcR were detected on both Ia<sup>+</sup> and Ia<sup>-</sup> CRL, and in addition, FcR were detected on 12% Ia<sup>-</sup> CR<sub>1</sub><sup>-</sup> cells. Clearly, there were more than 28% FcR-bearing cells, the majority of which bound either one or the other of the two immune complexes examined.

*Expression of CR<sub>1</sub> on Cells forming E rosettes.* Because 3% of normal blood lymphocytes contained CR<sub>1</sub> but lacked detectable B-cell-specific Ig and Ia de-

TABLE III  
Detection of FcR on Ia-Positive-vs. Ia-Negative-CRL with Different Immune Complex Systems

| Immune complex type            | FcR <sup>+</sup> cells detected              |  |  |
|--------------------------------|--|--|--|
|                                | Ia <sup>+</sup> CR <sub>1</sub> <sup>+</sup> | Ia <sup>-</sup> CR <sub>1</sub> <sup>+</sup> | Ia <sup>-</sup> CR <sub>1</sub> <sup>-</sup> |
|                                | %  |  |  |
| Anti-OVA-OVA                   | 1.2*   | 3.2  | 11.7   |
| Anti-IgA-IgA                   | 13.4   | 0.3  | 0.4  |
| Anti-OVA-OVA plus anti-IgA-IgA | 13.1   | 3.3  | 12.4   |

\* Averages from assay of five normal individuals.

TABLE IV  
CR<sub>1</sub> and Ia Expression in E-Rosette-Negative and E-Rosette-Positive (T-Cell) Fractions Isolated from Normal Blood

| Lymphocyte fraction | Marker combinations detected                 |  |  |  |
|---------------------|--|--|--|--|
|                     | Ia <sup>+</sup> CR <sub>1</sub> <sup>+</sup> | Ia <sup>+</sup> CR <sub>1</sub> <sup>-</sup> | Ia <sup>-</sup> CR <sub>1</sub> <sup>+</sup> | Ia <sup>-</sup> CR <sub>1</sub> <sup>-</sup> |
|                     | %  |  |  |  |
| Unseparated cells   | 13.6*  | 1.9  | 3.5  | 81   |
| E-rosette-negative  | 56   | 7  | 12   | 25   |
| E-rosette-positive  | 0.6  | 0.1  | 1.6  | 98   |

\* Averages from assay of five normal individuals.

terminants, assays were performed to determine if some CR<sub>1</sub>-bearing cells expressed the T-cell marker of E-rosette formation. Normal blood lymphocytes forming E rosettes were separated from E-rosette-negative lymphocytes by Ficoll-Hypaque centrifugation, and then each of the two lymphocyte fractions was examined by double-marker assay for EAC1-3b rosette formation and Ia antigens. E-rosette-negative fractions contained the vast majority of Ia<sup>+</sup> cells and <2% contamination with E rosettes. By contrast, 98–99% of cells in E-rosette (T-cell) fractions formed E rosettes and only 0.5–1.0% of cells expressed Ia antigens. The majority of cells in the E-rosette-negative fractions contained CR<sub>1</sub>, and these included 12% Ia<sup>-</sup> CR<sub>1</sub><sup>+</sup> cells (Table IV). By contrast, only 2.1% CR<sub>1</sub><sup>+</sup> cells were detected in T-cell fractions, including 1.6% Ia<sup>-</sup> CR<sub>1</sub><sup>+</sup> cells. Even though B-cell fractions contained a much higher proportion of Ia<sup>-</sup> CR<sub>1</sub><sup>+</sup> cells than did T-cell fractions, the B-cell fractions represented only 18% of the unseparated lymphocytes, whereas the T-cell fractions contained the remaining 82% of lymphocytes. Thus, it could be calculated that whole blood contained 2.2% (18% of 12%) E-rosette-negative Ia<sup>-</sup> CR<sub>1</sub><sup>+</sup> cells and 1.3% (82% of 1.6%) of E-rosette-positive Ia<sup>-</sup> CR<sub>1</sub><sup>+</sup> cells.

Parallel assay for EAC1-3d rosette formation in these same T-cell fractions revealed only 0.3% CR<sub>2</sub>-bearing cells, all of which contained Ia determinants (data not shown). Thus, the E-rosette marker was associated with only a minor proportion of CR<sub>1</sub>-bearing cells and was absent from CR<sub>2</sub>-bearing cells.

## DISCUSSION

The expression of C receptors is a well-recognized property of B cells, but there have been several conflicting reports of C receptors also present on T cells (6) and non-B cells active in antibody dependent cellular cytotoxicity (21, 22). The present study was undertaken because of the advent of several improved methods for detection of membrane markers and the availability of Ia as a reliable B-cell marker on Ig-posi-

tive and some Ig-negative lymphocytes. Although B-cell-specific surface Ig or Ia antigens were detected on the majority of CRL, a minor proportion of CRL lacked these markers and these included some CRL that apparently expressed the T-cell marker of E rosette formation. FcR were detected on all normal blood CRL, but qualitative differences in the FcR of Ia<sup>+</sup> CRL vs. Ia<sup>-</sup> CRL were recognized by their preferential binding of one or the other of two different immune complex systems.

In the past, many different types of studies have been performed in an attempt to determine whether the CRL were members of either the B- or T-lymphocyte population (23, 24). The first of such studies in mice demonstrated that the majority of CRL were killed by anti-Ig and C (23), whereas conversely the proportion of CRL was increased by treatment of lymphocytes with anti-thy-1 and C (25). Thus, the CRL were part of the Ig-bearing B-cell population but not the thy-1 bearing T-cell population. Subsequent direct studies with human lymphocytes demonstrated surface Ig by immunofluorescence on cells forming EAC rosettes, and an absence of C receptors on T cells forming E-rosettes (1, 2). However, whereas initial studies with whole IgG anti-Ig reagents indicated that all human blood CRL contained membrane Ig, significant proportions of Ig<sup>-</sup> CRL were also observed with these same reagents in both tonsils and spleen (2, 5). This apparent inconsistency was a stimulus to the present study, especially with the advent of more reliable methods for detecting surface Ig and because of the availability of surface Ia as an additional B-cell marker.

A variety of different observations on the selective expression of human Ia determinants has made it increasingly evident that Ia is a more reliable marker of cells in the B-lymphocyte lineage than is surface Ig. Among normal lymphoid cells, nearly all Ig-bearing cells and plasma-cell precursors express Ia, whereas Ia is undetectable on the vast majority of non-B and T lymphocytes (9, 10, 26). Furthermore, supporting evidence for Ia expression on Ig-negative pre-B cells has been provided by the demonstration of such characteristic pre-B cells in both normal marrow and marrow from patients with infantile hypogammaglobulinemia (27). Similarly, the essential absence of such Ia<sup>+</sup> Ig<sup>-</sup> cells in the blood from patients with infantile agammaglobulinemia supports the current concept that this disease results from a lesion in the developmental pathway of early B cells (10). In general, the assay of Ia antigens as a B-cell marker has certain advantages over surface Ig analysis. The interpretation of surface Ig data is complicated by the changing relationship of surface IgM and IgD during differentiation, as well as by the absence of Ig from pre-B cells and activated cells. In addition, technical problems in

the analysis of Ig can result from the presence of either autoantibodies to lymphocytes or FcR capable of binding immune complexes and serum IgG. However, it should also be emphasized that surface Ia analysis has other drawbacks that require caution. Some monocytes have surface Ia and B cells ultimately lose detectable Ia determinants during the terminal differentiation process into plasma cells (28).

The present studies illustrated the differences between whole IgG anti-Ig and F(ab')<sub>2</sub> anti-Ig reagents that were derived from the same antisera and demonstrated to have the same specificity and potency. This difference was still apparent after a 1-h incubation and three washes in 37°C buffer, suggesting that small quantities of plasma Ig may still have been present. Moreover, these experiments demonstrate that a considerable proportion of the cells labeled with the whole IgG-anti-Ig reagent were not labeled with the F(ab')<sub>2</sub> anti-Ig derivative and lacked C receptors entirely. These presumably represent the T cells with FcR previously identified as cells that secondarily bind the fluorescent reagent in complexed form (7). Even though in most normal individuals there was little difference in the proportion of positive cells detected with whole IgG anti-μ, δ vs. F(ab')<sub>2</sub> anti-μ, δ, it was also found, in some occasional individuals, that whole IgG-anti-μ, δ stained 10–50% more lymphocytes than did its F(ab')<sub>2</sub> derivative. Thus, for detection of membrane IgM and IgD, as well as IgG, it is preferable to use F(ab')<sub>2</sub> rather than whole IgG antibodies.

Tests with mixtures of EAC types confirmed previous findings (2, 5) that CR<sub>2</sub>-bearing cells (9.7% of lymphocytes) were a subpopulation of CR<sub>1</sub>-bearing cells (17.0% of lymphocytes). All normal blood CRL could be detected by rosette formation with either EAC14b or EAC1-3b but not with EAC1-3d. Nearly all cells bearing both CR<sub>1</sub> and CR<sub>2</sub> expressed Ig, whereas more than 5% of normal blood lymphocytes expressed CR<sub>1</sub> but not CR<sub>2</sub> and these lacked detectable membrane Ig. However, the CR<sub>2</sub> assay does not detect all normal B cells, because an average of 2% of lymphocytes expressed surface Ig and lacked CR<sub>2</sub>.

To exclude the possibility that some Ig<sup>-</sup> CRL might be nonlymphoid cells, EAC-rosetted cells were simultaneously examined for latex ingestion, peroxidase staining, and Wright-Giemsa morphology. Nonlymphoid cells in lymphocyte preparations included monocytes (20%) and immature neutrophils (5%), all of which were stained for peroxidase activity. More than 95% of peroxidase-positive cells ingested latex particles and thus were excluded from surface marker analysis. The remaining very minor proportion of peroxidase-positive latex-negative cells differed from Ig<sup>-</sup> CRL because most were CR<sub>1</sub><sup>+</sup> CR<sub>2</sub><sup>+</sup>, whereas Ig<sup>-</sup> CRL were CR<sub>1</sub><sup>+</sup> CR<sub>2</sub><sup>-</sup>. Indeed, previous studies of monocytes (29) and

immature neutrophils (30) have demonstrated that these cells very rarely express CR<sub>1</sub> in the absence of CR<sub>2</sub> and commonly contain either no C receptors, CR<sub>2</sub>, or CR<sub>2</sub> plus CR<sub>1</sub>. Thus, it is likely that most, if not all of the Ig<sup>-</sup> CR<sub>1</sub><sup>+</sup> cells identified in the present study were lymphocytes.

Of these Ig<sup>-</sup> CR<sub>1</sub><sup>+</sup> cells, slightly less than half bore Ia determinants and these were presumably Ig<sup>-</sup> members of the B-lymphocyte lineage.

Essentially all CRL were demonstrated to have FcR, however several different types of FcR assay systems were required to demonstrate FcR on the entire CRL population. This heterogeneity may have been involved in some previous reports that some CRL lacked FcR (31, 32). Four different soluble immune complex systems were examined for fluorescence labeling of FcR. Two of the complexes bound primarily to Ia<sup>+</sup> cells whereas the other two complexes bound primarily to Ia<sup>-</sup> cells. Detection of all cells with FcR required a mixture of two different complexes, one that preferentially bound to Ia<sup>+</sup> cells and another that preferentially bound to Ia<sup>-</sup> cells. Other investigators have also reported a heterogeneity of FcR on B cells vs. non-B cells (33, 34).

Table V summarizes the findings of this study. Five different CRL subsets were defined by the surface markers examined and these included 17% of peripheral blood lymphocytes. The first subset of CRL contained both CR<sub>1</sub> and CR<sub>2</sub>, while the remaining four subsets contained only CR<sub>1</sub>. This first subset contains the majority of Ig<sup>+</sup> CRL and would be the only subset detected if EAC1-3d were used to detect CRL. This is probably the explanation of the report that Ig-bearing cells and CRL were a completely overlapping homogeneous population of cells (35), especially in view of the use of EAC prepared with whole mouse serum as a source of C and thus EAC1-3d (4), a preparation that is known to detect primarily only CR<sub>2</sub> and fewer normal blood CRL than does an EAC1-3b preparation that detects CR<sub>1</sub> (2, 4). The first three CRL subsets are B cells because of their content of surface Ia determinants (8-10). These three B-cell CRL subsets may reflect

different stages of lymphocyte differentiation, rather than functionally different cell types. CR<sub>1</sub>, CR<sub>2</sub>, and FcR have been shown to be expressed sequentially during the process of granulocyte differentiation from immature bone marrow cells (30, 36), and studies of mouse B lymphocytes have demonstrated a sequential appearance of C receptors during B-cell maturation (37). The fourth and fifth CRL subset of Table V lacked both Ig and Ia determinants. The fifth subset, representing 1.1% of blood lymphocytes, not only lacked both Ig and Ia, but also formed E rosettes, a T-cell marker. However, these cells may not be T cells as there is an alternate possibility that they may be the CR<sub>1</sub>-bearing cells that mediate antibody-dependent cellular cytotoxicity (23, 38). Final classification of the fourth and fifth CRL subsets will require their isolation and function analysis.

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| TABLE V  |                 |            |                  |
|--|-----------------|------------|------------------|
| Surface Marker-Defined Subsets of Normal Blood CRL |                 |            |                  |
| C receptor type                                    | Surface markers | Proportion | Probable lineage |
|  |                 | %          |                  |
| CR <sub>1</sub> , CR <sub>2</sub>                  | Ia, FcR, Ig     | 9.4        | B cell           |
| CR <sub>1</sub>                                    | Ia, FcR, Ig     | 2.0        | B cell           |
| CR <sub>1</sub>                                    | Ia, FcR         | 2.4        | B cell           |
| CR <sub>1</sub>                                    | FcR             | 2.1        | ?                |
| CR <sub>1</sub>                                    | FcR, E-rosette  | 1.1        | ?                |

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