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TWO TYPES OF MURINE HELPER T CELL CLONE

I. Definition According to Profiles of Lymphokine Activities and Secreted Proteins

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A panel of antigen-specific mouse helper T cell clones was characterized according to patterns of lymphokine activity production, and two types of T cell were distinguished. Type 1 T helper cells (Th1) produced IL-2, interferon-γ, GM-CSF, and IL-3 in response to antigen + presenting cells or to Con A, whereas type 2 helper T cells (Th2) produced IL-3, BSF-1, and two other activities unique to the Th2 subset, a mast cell growth factor distinct from IL-3 and a T cell growth factor distinct from IL-2. Clones representing each type of T cell were characterized, and the pattern of lymphokine activities was consistent within each set. The secreted proteins induced by Con A were analyzed by biosynthetic labeling and SDS gel electrophoresis, and significant differences were seen between the two groups of T cell line. Both types of T cell grew in response to alternating cycles of antigen stimulation, followed by growth in IL-2-containing medium. Examples of both types of T cell were also specific for or restricted by the I region of the MHC, and the surface marker phenotype of the majority of both types was Ly-1+ LYT-2-, L3T4+. Both types of helper T cell could provide help for B cells, but the nature of the help differed. Th1 cells were found among examples of T cell clones specific for mouse B cell alloantigens, fowl γ-globulin, and KLH. The relationship between these two types of T cells and previously described subsets of Th1 cell was discussed.

Mouse helper T cells (Th) appear to be fairly uniform when judged by the commonly used surface markers, bearing Ly-1 and L3T4 but not Lyt-2 antigens. When assessed by functional criteria, however, at least two types of Th cell have been described (1-6). These subtypes of Th cell have been described mainly in uncloned populations, but certain differences between them appear to be consistent. A synthesis of the work of several groups provides the following description of these T cells. One type of Th cell (Th1) helps B cells in a linked, antigen-specific manner, is "monogamous" in limiting dilution cultures, and is required early in the response. These T cells may also help in an unlinked manner at high antigen concentrations (7). The other type of Th cell (Th2) helps B cells in a nonlinked manner, is "polygamous" in limiting dilution cultures, and is required later in the response. In addition, Th2 cells possess determinants that map to the I region of the major histocompatibility (MHC) and bind to nylon wool, whereas Th2 cells lack both of these properties. The determinants on Th2 cells that map to the I region may actually represent structures that are controlled by the I region but are not coded by the I region (8).

We have found that in a large panel of antigen-specific and autoreactive Th cell clones, we were able to divide the clones into two distinct groups. These groups were originally defined on the basis of patterns of lymphokine synthesis, but can also be distinguished by their characteristic mode of B cell help. The properties of these two sets of Th cells agree in many respects with the two sets of Th cells described above, and we have used the nomenclature of Tada et al. (11) to describe Th1 and Th2 cells. In this study we describe the derivation of antigen-specific T cell clones of both types, and their evaluation according to the distinctive patterns of lymphokine activities produced after antigen or lectin stimulation. We have also analyzed the supernatant proteins produced after concanavalin A (Con A) stimulation and biosynthetic labeling, and have found characteristic patterns associated with each type of Th cell clone.

MATERIALS AND METHODS

Mice. C57BL/6, CBA/J, and BALB/c mice were obtained from The Jackson Laboratory (Bar Harbor, ME) and the Institute for Medical Research (San Jose, CA). Recombinant inbred mice used for MHC restriction typing were a generous gift of Dr. H. McDevitt.

Antigens and antibodies. Chicken red blood cells (CRBC) were obtained from six partially inbred lines of chickens, homoygous for MHC alleles but differing in other blood group antigens, maintained at PMK Farms, Vacaville, CA. Keyhole limpet hemocyanin (KLH) was obtained from Pacific Biomarine, Venice, CA, and fowl γ-globulin (FGG) was obtained from Cappel Laboratories, Cochranville, PA. Monoclonal antibody specific for mouse interleukin 2 (IL-2) was from the S486 hybridoma obtained by fusing Sp2/0 hybridoma cells with spleen cells from a rat immunized with concentrated LDL-1 supernatant [manuscript in preparation].

Cell lines. The COS monkey cell line was obtained from F. Lee. The J5 mouse T cell line (9) was obtained from S. Strober, the
NF560 cell line was obtained from J. Ihle through D. Rennick, and the MC/9 mast cell line (10) and C1.Ly-1/9 T cell line (11) were obtained from G. Nabel. The MM3 mouse mast cell line was established from BALB/c mouse bone marrow and maintained with supernatant from Con A-induced C1.Ly-1/9 cells. All cells were grown in RPMI 1640 supplemented with 0.05 mM 2-mercaptethanol, 10% fetal bovine serum (FBS), and growth factors where necessary: recombinant mouse IL-2 (kindly provided by G. Zarafsky) for HT2, Con A-induced spleen-conditioned medium (11) for C1.Ly-1/9, and supernatant from Con A-induced C1.Ly-1/9 T cells for NF560, MM3, and MC/9.

Establishment of T cell lines. T cell lines were established as described (12) except that T cells were prepared either by adoptive transfer or by limiting dilution in vitro. T cell lines specific for alloantigens were cloned directly from the spleens of immunized mice by limiting dilution on irradiated allogeneic stimulator cells. T cell lines were grown on alternate cycles of antigen stimulation followed by growth in IL-2-containing medium. Antigen stimulation was carried out by incubating T cell lines at 1 x 10^6 cells/ml with antigen and 2 x 10^6 syngeneic spleen cells/ml in RPMI 1640 + 10% FBS + 0.05 mM 2-mercaptoethanol + recombinant mouse IL-2 (400-800 U/ml, see below). After 24 hr, the cultures were expanded in the same medium.

Stimulation of T cell clones. For Con A stimulation, T cells were harvested by centrifugation and were resuspended in RPMI 1640 containing 0.01 mg/ml Con A (Calbiochem, La Jolla, CA) with or without 5% FBS. Supernatants were harvested after 24 hr. T cells (5 x 10^6/ml) were stimulated with antigen (0.02% CRBC or 0.015 mg/ml Ficoll or 0.5 x 10^6 spleen cells/ml) that was harvested after 24 hr. The supernatants were harvested and were tested for lymphokine activity. Allogeneic stimulations [MC/9 or MC/0] were carried out similarly except that no exogenous antigen was added.

Transfection of lymphokine cDNA clones. COS cells were transfected with cDNA clones for mouse IL-3 (13), interferon-γ, and granulocyte-macrophage colony-stimulating factor (GM-CSF) as described (14). Supernatants containing lymphokine activity were harvested from 3 to 5 days after transfection. Plasmid DNA for these three lymphokine cDNA clones was a generous gift of R. Arai.

Bioassays. The colorimetric MTT (3,4-dimethyl-2-thiazolyl-2,5-diphenyl tetrazolium bromide) proliferation assay (15) was used for all assays. The assay medium was RPMI 1640 containing 0.05 mM 2-mercaptoethanol and 10% FBS. Samples were diluted twofold serial dilutions in 96-well, flat-bottomed trays (Falcon) in a volume of 0.05 ml. Target cells [10^5, for MC/9, MM3, and NFS60, and 2 x 10^6/well for HT2] were then added in a vol of 0.05 ml and the trays incubated at 37°C for 22 hr. MTT solution (0.1 ml of 5 mg/ml stock in phosphate-buffered saline) was added to each well, and incubation was continued for another 2 hr at 37°C. All wells then received 0.15 ml of 0.04 N HCl in isopropanol, and after thorough mixing to dissolve the dark blue crystals, the optical density was measured on a Dynatech MR580 Microelisa reader by using a test wavelength of 570 nm and a reference wavelength of 630 nm. The results were transferred directly to an Apple II computer and the units of activity were calculated. One unit is defined as the amount of cpm obtained in 0.1 ml, resulted in a signal in the MTT assay equal to 50% of the maximum signal. In all assays, the absorbance of the blank (cells but no factor added) was subtracted from all values.

Bioactive labeling of T cells. T cells were labeled with 35S methionine after Con A stimulation as described (8). The radioactive secreted proteins were analyzed by SDS-PAGE by using the buffer system of Laemmli (16).

Protein separation methods. Secreted proteins from Con A-induced T cells were concentrated in an Amicon ultrafiltration cell (YM3 membrane) and were applied to a Vydac C4 (Separations Group, Hesperia, CA) reverse phase high pressure liquid chromatography (HPLC) column. Proteins were eluted by a gradient from 25% acetonitrile and 0.1% trifluoroacetic acid to 80% acetonitrile and 0.1% trifluoroacetic acid over a 4 ml/min. Serial dilutions of the 1 mm fractions were tested for bioactivity and the units of growth factor activity were calculated. SDS-PAGE was carried out by the methods of Laemmli (16).

Analysis of cell surface phenotype. The surface antigens of T cell lines were evaluated by flow cytometry after reaction with the following antibodies, anti-Ly-1, 53-7, anti-Ly-2, ATCC no. TIB104, anti-Ly-3, ATCC no. TIB107, and anti-LY4, ATCC no. TIB207.

T cell supernatants were tested for the ability to stimulate enhanced polyclonal secretion of IgG1 and IgE by lipopolysaccharide (LPS)-stimulated splenic B cells as described (17). After 7 days, the levels of IgG1 and IgE in the culture supernatant were measured by an isotype-specific ELISA assay (8). The inducing factor was shown to be LPS because monoclonal anti-LPS (18) did not alter the response of HT2 or IL-2 to the supernatant (Fig. 1C). Thus, the cell line HT2 can be used to examine the ability of supernatant to induce the production of IL-2 (19). The results confirm that HT2 is a useful system for studying the production and function of this cytokine.

RESULTS

Characteristics of bioassays. A large panel of antigen-specific T cell lines was analyzed by using several lymphokine bioassays. The cell lines could be grouped into two sets. T1 and T2, on the basis of the characteristic pattern of bioactivities found in their supernatants after Con A or antigen stimulation. We used several target cell lines in bioassays to detect these lymphokine activities. Some of these assays detect more than one factor, and some activities are influenced by the presence or absence of other lymphokines. We have characterized some of these interactions on three target cell lines to use the bioassays as more precise tools for determining the presence or absence of certain lymphokines. In particular, we have established "dominant" assays, i.e., bioassays in which a lymphokine activity is not influenced by the presence of T1 or T2 supernatants. In the description of the bioassays that follows, we have used the LB2-1 T cell clone as the representative T1 cell example and MB2-1 as the T2 example.

HT2 assay. The mouse T cell line HT2, originally established by J. Watson (9), is commonly used as an assay for mouse and human IL-2. We have used this line for IL-2 assays, and have also used it to assay another lymphokine activity in supernatants of certain T cell clones. Con A does not influence the HT2 cell line at the concentrations present in the samples (results not shown). Figure 1A indicates that HT2 proliferated equally well in response to saturating amounts of either recombinant IL-2 or the Con A-induced supernatant from LB2-1 (the T cell clone from which the recombinant cDNA clone for IL-2 was derived) (14). The addition of supernatant from the MB2-1 T cell line did not influence the stimulation due to IL-2 derived either from recombinant sources or LB2-1 supernatant (Fig. 1B). Taken together, these results suggest that HT2 cells respond to IL-2 and that this stimulation is not influenced by other factors present in induced LB2-1 or MB2-1 supernatants (examples of T1 and T2 cells, respectively). Figure 1A also demonstrates that the supernatant of induced MB2-1 cells contained an activity that stimulated the HT2 cell line to a lesser extent than IL-2, even at saturating amounts of supernatant. Similar results have been obtained by others (D. Rennick, personal communication). We have used a monoclonal antibody specific for mouse IL-2 to demonstrate that this second activity was distinct from IL-2. The S4B6 monoclonal antibody is a rat anti-mouse IL-2 that recognizes mouse but not human IL-2, and appears to have a high affinity for mouse IL-2 because it completely inhibits the biological activity of IL-2 at low antibody concentrations (manuscript in preparation). The bioactivity in the T2 supernatant was unaffected by the monoclonal antibody S4B6, whereas IL-2 activity could be completely inhibited (Fig. 1C).

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Addition, HT2 cells can also be used to detect another activity in the T2 supernatants. This second activity is obscured if IL 2 is present in the sample, because the strong IL 2 signal is dominant.

Separation of lymphokine activities. Additional evidence for the separate identities of IL 2 and T cell growth factor 2 (TCGF2), and the absence of TCGF2 in LB2-1 supernatants was obtained by column chromatography. Con A-induced supernatants from LB2-1 and MB2-1 cells were separated by chromatography on a C4 reverse phase HPLC column, and individual fractions were assayed for activity in the HT2 assay. The HT2 growth factor activities from these two cell lines eluted at very different times (Fig. 2), and each cell line produced only one activity, i.e., LB2-1 did not produce a TCGF activity eluting at the same position as the TCGF2 activity from the MB2-1 sample. Neither peak of activity could be due to Con A, which elutes at a different time. The characteristically different titration curves of IL 2 and TCGF2 from LB2-1 and MB2-1 respectively were also seen in the assay of these column fractions (results not shown).

NF560 assay. The NF560 cell line proliferated in response to recombinant IL 3 and also in response to both LB2-1 and MB2-1 supernatants (Fig. 3A). The level of proliferation in response to saturating amounts of LB2-1

Figure 1. Response of HT2 cells to IL 2 and a second TCGF activity
A. Dilutions of Con A-induced LB2-1 and MB2-1 cell supernatants and recombinant mouse IL 2 were tested for activity in the HT2 proliferation assay. The starting dilutions in the first well were: LB2-1, 1/4; MB2-1, 1/1; recombinant IL 2, 1/4000. (--) LB2-1; (---) MB2-1; (----) rIL 2.
B. Dilutions of MB2-1 supernatant were tested for an effect on the proliferation of HT2 cells in response to a constant amount of IL 2 (400 U/ml) supplied as a dilution of Con A-induced LB2-1 supernatant (----) or recombinant mouse IL 2 (---). A titration curve of IL 2 in LB2-1 supernatant is shown for comparison (-----). Starting dilutions were: LB2-1, 1/4; MB2-1, 1/1.
C. Dilutions of ascites fluid containing the monoclonal anti-IL 2 antibody S4B6 (starting at 1/40) were assayed for their effect on the response of HT2 to a constant amount of recombinant mouse IL 2 (80 U/ml, ---) or MB2-1 supernatant (1/40 final dilution, ----).

Figure 2. Reverse phase HPLC of IL 2 and TCGF2. Supernatants from Con A-induced LB2-1 and MB2-1 cells were concentrated and separated on a C4 column as described in Materials and Methods. Dilutions of each fraction were then assayed on HT2 cells, and the units of activity per milliliter of the column fraction were calculated.
supernatant was significantly lower than the responses to the other two IL 3 sources. Mixtures of LB2-1 supernatant with recombinant IL 3 resulted in the inhibition of the strong IL 3 signal. Interferon-γ also inhibited the proliferation of NFS60 cells in response to IL 3 (Fig. 3b). Because LB2-1 cells produce large amounts of interferon-γ, this could explain the lower maximum proliferation level of NFS60 cells in LB2-1 supernatant. Thus, NFS60 responds strongly to IL 3, and the IL 3 response can be partially inhibited by an activity in Tn1 supernatants, possibly interferon-γ.

MM3 assay. The MM3 mast cell line proliferated strongly in response to MB2-1 supernatant and weakly in response to LB2-1 supernatant or recombinant IL 3 (Fig. 4A). When LB2-1 and MB2-1 supernatants were mixed, the higher signal was obtained (Fig. 4B). These results suggest that another activity in MB2-1 supernatants, in addition to IL 3, was responsible for the maximum proliferation of MM3 cells. This second activity has been separated biochemically from IL 3 and has been shown to require IL 3 as cofactor for biological activity (unpublished results). Similar results have been obtained by Rennick and Smith [19]. This activity (which we shall refer to as mast cell growth factor 2; MCGF2) was not inhibited by any activity in LB2-1 supernatant (Fig. 4B). Growth of the MM3 cell line was used as a specific and dominant assay for the MCGF2 activity by including saturating amounts of LB2-1 supernatant containing IL 3 in the assay medium. Under these conditions, supernatants of Tn1 cell lines did not cause additional stimulation of MM3 cells, whereas Tn2 cell supernatants gave a strong, dose-dependent signal (Fig. 4B).

Classification of T cell clones according to lymphokine activities. Figure 5 shows the typical activity profiles of several Tn1 and Tn2 cell lines in the HT2, MM3, and NFS60 assays. Tn1 cells gave results consistent with the production of IL 2, IL 3, and interferon-γ, but not MCGF2. In contrast, Tn2 cells did not appear to produce IL 2 or interferon-γ but did produce IL 3 and the two activities described above as TCGF2 and MCGF2. It is important to note that these sets of activities were coordinate, e.g., IL 2 and interferon-γ activities were produced by the same lines, and TCGF2 and MCGF2 activities were found together. The lymphokines that we infer were...
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produce these two sets of T cell lines are summarized in Table I. IL 2 was evaluated by stimulation of HT2 cells, and MCGF2 was measured by the stimulation of MM3 cells in the presence of saturating amounts of IL 3. TCGF2 was evaluated by its weak stimulation of HT2 cells in the absence of IL 2 by using separation by HPLC.

in some cases to remove IL 2. IL 3 was evaluated by combining information from proliferation of NSF60 and MM3 cell lines and HPLC separations (unpublished results). Interferon-γ was evaluated by combining data from the inhibition of NSF60 proliferation, la induction on P388D1 cells, antiviral activity, immune precipitation (see Fig. 8),4 and inhibition of IgE-enhancing activity (17). B cell stimulating factor 1 (BSF1) activity was evaluated from la induction assays on B cells. IgG- and IgG1-enhancing activities were determined by measuring the IgE and IgG1 levels at day 7 in LPS-stimulated cultures of T-depleted spleen cells (17).

Production of lymphokine activities in response to antigen. In the experiments described above, Con A was used to stimulate T cells to produce lymphokines without interference by spleen cells. We also assayed supernatants from T cells stimulated with antigen + irradiated spleen cells, or with MHC alloantigens. In each case, the lymphokine activities induced by antigen or by Con A were identical, i.e., the activities detected were dependent on the T cell line and not on the method of induction. Representative examples are shown in Figure 6.

Classification of T cell lines according to B cell-stimulating activities. Examples of the two sets of T cell lines were also tested for their effect on LPS-stimulated B cells. Activities in T cell supernatants have recently been described that enhance IgE production by over 100-fold (17) and IgG1 production by 10-fold (17, 20) in LPS-activated B cells. When supernatants from our panel of T cell lines were tested for these activities, the Tn,2 cells were found to produce IgE- and IgG1-enhancing activities, whereas Tn,1 cells were consistently negative in this assay (Table II). Interferon-γ is known to be a potent inhibitor of both enhancing activities (17). Because Tn,1 cells produce large amounts of interferon-γ, the absence of these enhancing activities in the Tn,1 supernatants does not prove that the factor or factors that mediate this activity are absent. Some T cell supernatants also contain an activity that stimulates the expression of la antigens on normal B cells. This activity, as well as the IgG1- and IgG-enhancing activities, may be mediated by the lymphokine BSF1 (18, 20–22). When Tn,1 and Tn,2 cell supernatants were assayed for the ability to induce la on B cells, Tn,2 supernatants were found to contain substantial amounts of this activity, whereas Tn,1 cell supernatants did not (Table III). la induction by Tn,2 supernatants is not inhibited by purified interferon-γ (R. Coffman, unpublished observations).

Classification of T cell clones according to surface antigens. Examples of the same panel of T cell clones were tested for surface markers by using monoclonal antibodies directed against Lyt-1, Lyt-2, and L3T4 antigens (Table IV). In all cases tested, both Tn,1 and Tn,2 cell clones were L3T4+ and Lyt-2+. The majority of both types of Tn,1 cell clones were also Lyt-1−, although two Tn,2 and one Tn,1 clones were negative for this antigen. The Lyt-1 determinant may be preferentially lost during prolonged in vitro culture, because the C1.Lyt-1/9 cell line was originally Lyt-1+ (11). Representative examples are shown in Table IV.

Specificity or restriction for MHC determinants. Several T cell clones of both types were tested for MHC restriction or specificity by stimulation with spleen cells from recombinant inbred mice of the B10 series. The
results in Table V demonstrate that the MHC restriction of the T cell clones specific for foreign antigens was consistent with determinations coded by the I region of the MHC, and the T cell specific for alloantigens also recognized determinants that mapped to the I region.

**Secrec ted proteins synthesized by Tn1 and Tn2 cells.**

Several Tn1 and Tn2 cell lines were labeled with $[^{35}]$S methionine after Con A stimulation, and the resulting induced secreted proteins were analyzed by SDS-PAGE and fluorography. We have shown previously that under these conditions, T cell clones secrete large amounts of proteins in the 10,000 to 30,000 dalton range in response to Con A, and almost all of these proteins are induction specific. Although some differences were seen among all cell lines, Tn1 and Tn2 cell lines appeared to constitute two distinct and recognizable groups (Fig. 7). In particular, the discrete band at 16,000 daltons appeared to be characteristic of Tn2 clones. A group of bands in the 17,000 to 18,000 dalton region was characteristic of Tn1 clones. Immunoprecipitation with an antiserum specific for interferon-γ demonstrated that these bands were due to interferon, and that these components were absent in Tn2 samples (Fig. 8). The specificity of this antiserum has been demonstrated.

**DISCUSSION**

In our panel of antigen-specific Tn cells, we have been able to group the clones into two clearcut groups according to a variety of criteria. These include lymphokine bioactivities, helper function, and biosynthetic labeling patterns. T cell clones could be assigned to one or the other of these subclasses by using any of these three criteria, and the other properties were consistent with the assignment. The concordance of these different assays as T cell diversity, and the derivation of examples of both types of Tn cells from four different strains of mouse, suggest that these groups of Tn cells represent real subdivisions of the Tn cell class that may have important relevance in vivo.

Although the two groups of Tn cells showed very different biological activities, they shared several properties that are typical of helper cells generally. All were positive for the L3T4 surface antigen, and all lacked the Lyt-2 antigen. Examples of both types of Tn cells were restricted by or specific for the I region of the MHC, and examples of both types provide B cell help (results not shown). The lack of distinctive surface markers may have hindered past efforts to identify the two types of helper cell.

The bioactivities detected in activated Tn1 supernatants were consistent with the synthesis of IL-2, IL-3, and interferon-γ. The presence of these lymphokines in one T cell clone was also demonstrated by recombinant cloning of IL-2 (14) and Northern blot RNA analysis of IL-3 and interferon-γ (9). All three lymphokines have also been demonstrated by biosynthetic labeling and immunoprecipitation in LB2-1 supernatants. In contrast, Tn2 clones did not synthesize detectable amounts of IL-2 or interferon-γ assayed by bioactivity, immunoprecipitation, or sequence-specific probing of a Tn2 cDNA library (K. Arai, personal communication). Tn2 clones also produced several less defined lymphokine activities that were not detected in Tn1 supernatants. These activities include IgG1- and IgG-enhancing activities and Ia-inducing activity, all of which may be mediated by BSF1 (18, 20-22), a T cell activity that was distinct from IL-2, and a MCGF activity distinct from IL-3. These latter two activities have not yet been biochemically resolved from one another, and all T lines tested made both activities or neither activity. We are currently attempting to identify the molecule(s) responsible for these activities. We also have preliminary evidence that both Tn1 and Tn2 cell
lines can synthesize GM-CSF, as a result of data from bioactivity assays and screening of recombinant cDNA libraries (unpublished results).  

The supernatants of the T cell clones used in these studies were rich sources of lymphokine activities. Although we used clonal assay lines to detect several of the biological activities, these assay lines did not always detect only one lymphokine. In some cases, more than one activity was detected by one cell line, and certain activities interacted with one another, either positively or negatively. Some examples include the inhibition by interferon-y of IL 3-induced proliferation of NFS60 cells and of the IgE and IgG1, enhancing activities on LPS-stimulated B cells, the synergistic effect of IL 3 and MCGF2 on the growth of MM3 mast cells, and the response of HT2 cells to both IL 2 and a second factor that gave a signal in the HT2 assay. For the conclusions described above, we have relied mainly on "dominant"
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TABLE V

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<sup>a</sup> The allelics for the A<sub>α</sub>, A<sub>β</sub>, E<sub>α</sub>, and E<sub>β</sub> genes are shown.
<sup>b</sup> Units MCGF/ml in supernatant after stimulation by antigen + antigen-presenting cells from the specified mouse strain.
<sup>c</sup> Less than 10 U/ml.
<sup>d</sup> Not determined.

Figure 7. Biosynthetically labeled induced, secreted proteins of T cell clones. Type 1 and type 2 T cell lines were induced with Con A and were labeled with [35S]methionine for 2 hr starting 4.5 hr after Con A stimulation. The supernatants were analyzed by SDS-PAGE. Samples A to H represent Tα1 cell clones, and samples I to P represent Tα2 cell clones. The arrows indicate the position of m.w. markers (in kilodaltons). Experiment 1: A = MD13-5.1, B = MD13-10, C = MD13-5.1, D = H22-6, E = H39-34, F = A, G = H39-2, H = MDRK. Experiment 2: D = MD13-5.1, E = MD13-10, F = MDRK, G = H22-6, H = A, I = MD13-5.1, J = H39-34, K = H39-2, L = H39-72.

Figure 8. Synthesis of interferon-γ by Tα1 but not Tα2 clones. Aliquots of the samples described in Figure 7, experiment 2 were subjected to indirect immunoprecipitation with rabbit anti-mouse interferon-γ antiserum, and the resulting precipitates were analyzed by SDS-PAGE along with aliquots of the unprecipitated material. A = M264-37, B = M264-15, C = MD13-5.1, D = M264-15, E = M264-20, F = M264-39, G = C71-1, H = M264-20.

The two types of T<sub>α</sub> cell clones are consistent from one experiment to another. These findings suggest that the Tα1 and Tα2 phenotypes are stable and represent significant functional differences between two sets of Tα<sub>1</sub> cells. The T cell clones that we have designated Tα<sub>1</sub> may be equivalent to the la-negative helper cells described by Tada et al. (1) and Swierkosz et al. (2), which do not bind to nylon wool and are required early in an in vitro response. They may also correspond to the antigen-linked "monogamous" T<sub>α</sub> cells described by Waldmann (3) and Imperiale et al. (4). The clones that we have described as Tα2 produce BSF-1, which could account for the strong, unlinked B cell help provided by the second type of T<sub>α</sub> cells described by the same investigators. In addition to their nonspecific B cell help, the second type of Tα cell has been characterized as adherent to nylon wool (1), positive for "la" antigens (1, 2), and required later in the in vitro B cell response (1, 2). The full range of Tα<sub>1</sub> cell phenotypes may be broader, however, and Melchers et al. (5) and Kim et al. (6) have described results consistent with a more than two helper subpopulations. In particular,
TWO TYPES OF CLONED HELPER T CELL

...the data of Kim et al. (6) when using T cell clones suggest four different phenotypes assessed by the pattern of B cell help, and therefore the two major subdivisions of Tn cells that have described according to lymphokine production may be additionally subdivided when more data are available. We have obtained data on several Tn1 clones that suggest that these may differ in B cell helper function (manuscript in preparation), and the patterns of bio synthetically labeled secreted proteins suggest additional differences between the T cell clonal. Although similarities could be seen among all Tn1 clones and between all Tn2 clones, there were individual differences between the clones, especially in the Tn2 group. The presence or absence of some of the proteins in particular T cell clones suggest that additional bio assays may reveal functional heterogeneity within the Tn1 and Tn2 groups. This is also suggested by the two-dimensional electrophoresis results of Kettman and Lefkovits (23), who argue for considerable T cell heterogeneity.

There appears to be some preference for the type of Tn cell clone isolated in different experiments. We have isolated CRBC-specific T cell clones from three different mouse strains, and in over 200 antigen-specific clones, we have not found any Tn2 examples. In contrast, FGG-specific clones in one experiment were all Tn2. Both Tn1 and Tn2 clones were found among all specific Tn1 cells specific for the I region of the MHC. This apparent association of certain antigen specificities with one or another type of T cell may represent genuine differences in the induction of T cells in a manner analogous to the induction of different antibody isotypes by different antigens. In fact, these two phenomena may be related, because the Tn1 and Tn2 cells may have differential effects on the Ig isotype produced in vitro. Tn2 cells produce activities that strongly enhance IgM and IgG1 production relative to other isotypes in a polyclonal activation system, whereas Tn1 cells produce interferon-γ, which strongly inhibits the enhancing activities in Tn2 supernatants. If the two types of Tn cells produce similar activities during an in vivo immune response, the following hypothesis can be advanced. An antigen, such as FGG adsorbed to alum, that induces a substantial IgE response may do so by preferentially inducing Tn2 cells, whereas CRBC, which induce large IgM but very small IgG responses, may do so by preferentially activating Tn1 cells that help IgM but suppress IgE production. We are also investigating the association of the type of Tn cell in relation to the antigen and the adjuvant used for immunization.

The derivation of two distinct types of Tn cell clones raises the question of the total diversity of T cell phenotypes. The procedures used to generate our T cell clones may be highly selective for particular types, and it is quite possible that other T cell types exist in vivo. This is underscored by the uniform phenotype of our anti-CRCB T cell lines, which were all Tn1. Only when we examined T cell clones specific for FGG or allotigen did we discover antigen-specific T cells of the second phenotype. The study of additional antigens or alterations in culture conditions may reveal additional types of Tn1 cell.

The two types of helper cells described in this report differ in several respects, and yet they have not been extensively described before at the clonal level. Several features of these cells may have contributed to reducing the number of Tn2 clones isolated. Because Tn2 cells are dependent on IL-2 for growth, and yet do not produce IL-2, these cells may be grown on a constant supply of exogenous IL-2. In addition, we have found that the Tn2 clones do not grow as rapidly as Tn1 clones, and they may have extra requirements for growth or a limited lifespan. We have been much more successful in growing large numbers of Tn1 clones than Tn2 clones.

Several questions about the two types of Tn cells now need to be answered. Because both types bear the same cell surface markers as the delayed-type hypersensitivity (DTH) effector cells, is one or both cell types identical to the DTH cell? What is the relative contribution of each type of T cell to normal in vivo responses? Do the differences between Tn1 and Tn2 cells represent separate lineages of Tn cells, or do the two types represent different stages of the same lineage? Is the apparent selectivity of the antigen or adjuvant for Tn1 or Tn2 a real phenomenon, and what determines this selectivity? How is IL-2 regulated coordinately with IL-2 and interferon-γ in Tn1 cells and yet noncoordinately in Tn2 cells? The T cell clones described in this report should be useful in answering these and many other questions.

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Note Added in Proof: We have recently obtained evidence from serological dataset[s] and recombinant DNA cloning of BSF-16 that the activities described as MCGF2 and TCGF2 are mediated by BSF-1.

REFERENCES


