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*J Immunol* 2005; 175:5-14; ;
http://www.jimmunol.org/content/175/1/5.citation

The Journal of Immunology

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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, BSF1, 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 conserved 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 chicken RBC and mouse alloantigens. Th2 cells were found among clones specific for mouse alloantigens, fowl γ-globulin, and KLH. The relationship between these two types of T cells and previously described subsets of T helper cells is 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 uncultured 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 Th1 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 T cells agree in many respects with the two sets of Th cells described above, and we have used the nomenclature of Tada et al. (1) 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; homogous for MHC alleles but differing in other blood group antigens, maintained at PMK Farms, Vacaville, CA. Keyhole limpet hemocyanin (KLH) was obtained from Pacific Bionar, 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 LTB1 supernatant [manuscript in preparation].

Cell lines. The COS monkey cell line was obtained from F. Lee. The HT2 mouse T cell line (9) was obtained from S. Strobos, the
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NF560 cell line was obtained from J. Hille through D. Rennick, and the MC/9 mast cell line (10) and CI.1-Ly-1/9 T cell line (11) were obtained from G. Nabel. The MM3 mouse mast cell line was established by D. Hilscher from a mouse strain similar in vivo to the MC/9 cell line. It was maintained with supernatant from Con A-induced CI.1-Ly-1/9 cells. All cells were grown in RPMI 1640 supplemented with 0.05 mM 2-mercaptoethanol, 10% fetal bovine serum (FBS), and growth factors where necessary: recombinant mouse IL-2 (kindly provided by G. Zweier) for HT2, Con A-induced spleen-Conditioned medium (11) for CI.1-Ly-1/9, and supernatant from Con A-induced CI.1-Ly-1/9 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 primed either by adoptive transfer or by cultivation in vitro. T cell lines specific for alloantigens were cloned directly from the spleens of immunized mice by limiting dilution without prior bulk culture in vitro. T cell lines specific for alloantigens were cloned directly from the spleens of immunized mice by limiting dilution without prior bulk culture in vitro. T cell lines specific for alloantigens were cloned directly from the spleens of immunized mice by limiting dilution without prior bulk culture in vitro.

Stimulation of T cell clones. For Con A stimulation, T cell clones 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 10^5/ml) were stimulated with Con A (0.02% CRBC or 0.015 mg/ml Fc) or 5 x 10^5 spleen cells/ml in RPMI 1640 supplemented with 0.05 mM 2-mercaptoethanol and 10% FBS. After 24 hr, the supernatants were harvested and were tested for lymphokine activities. Allogeneic stimulations (MHC or Mls) were carried out similarly except that no inorganic antigen was added.

Transfection of lymphokine cDNA clones. COS cells were transfected with cDNA clones for mouse IL 3 (13), interferon-g, 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. Arky.

Bioassays. The colorimetric MTT proliferation assay (15) was used for all assays. The assay medium was RPMI 1640 containing 0.95 mM 2-mercaptoethanol and 10% FBS. Samples were diluted 1:200 in 96-well, flat-bottomed tissue culture (Falcon) in a volume of 0.05 ml. Target cells (10^5/ml for MC/9, MM3, and NSF60, and 2 x 10^5/ml for HT2) were then added in a vol of 0.05 ml and the cells incubated at 37°C for 6 hr. MTT solution (0.01 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 in 0.1 ml, resulting 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 cell clones. T cell clones were labeled with 35S methionine after Con A stimulation as described. 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 cell lines were concentrated in an Amicon ultrafiltration cell (YM3 membrane) and were applied to a Vydac C4 Separation 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 in 0.4 min. Serial dilutions of the 1 min fractions were tested for bioactivity and the units of growth factor activity were calculated. SDS-PAGE was carried out by the method of Laemmli (16).

Analysis of cell surface phenotype. The surface antigens of T cell lines were analyzed by flow cytometry after reaction with the following monoclonal antibodies: anti-Lyt-1, 53-7, 53-8, 53-9, 53-10, and 53-12; anti-Lyt-2, 53-7, 53-8 (ATCC no. TIB103); anti-Lyt-2, 53-6, 53-7, 53-9, 53-10, 53-12, and anti-Ly-3, 53-8 (ATCC no. TIB107); and anti-Ly-5, 53-8 (ATCC no. TIB107).

T cell supernatants were tested for the ability to stimulate enhanced polysaccharide secretions of IgG1 and IgE by lipopoly-

Saccharide (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. The inducing factor was measured by the growth of medium 199 cells in the presence of supernatant from Con A-induced CI.1-Ly-1/9 cells.

Bioactive labeling and immune precipitation. T cells were stimulated with Con A and were labeled with 35S methionine as described. Supramolecular complexes were precipitated by using either normal rabbit serum or a rabbit anti-mouse interferon-γ antiserum (Enzo Biochem, New York, NY) by described methods.

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 characteristics of the 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 assays 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, or both. The bioassays that follow, we have used the LB1 or T cell line as the representative T1, T2, or T3 example, respectively.

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 sample (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 line from which the recombinant cDNA clone for IL-2 was derived). The addition of supernatant from the LB2-1 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 both 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 S4Be 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 S4Be, whereas IL-2 activity could be completely inhibited (Fig. 1C). Thus, the cell line HT2 can be used as a dominant assay for IL-2, i.e., the response of HT2 to IL-2 is not altered by other T1 or T2 supernatant activities. In
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addition, HT2 cells can also be used to detect another activity in the T₉2 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).

NFS60 assay. The NFS60 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, 1/4; 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 (-----). Starring dilutions were: LB2-1, 1/4; MB2-1, 1/4. C. Dilutions of ascites fluid containing the monoclonal anti-IL 2 antibody 4406 (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).

Figure 3. Response of NFS60 to lymphokines. A. Dilutions of supernatants of Con A-induced T cells or COS cells transfected with recombinant cDNA clones were assayed for their effect on NFS60 cells. Starting dilutions were: LB2-1 supernatant, 1/4 (--- —); MB2-1 supernatant, 1/1 (— —); COS IL 3, 1/40 (— —). B. Dilutions of supernatants of Con A-induced LB2-1 and MB2-1 cells and COS cells transfected with the cDNA clone for interferon-γ were assayed for their effect on the proliferation of NFS60 cells in response to a constant amount of recombinant IL 3 (100 U/ml). Starting dilutions were: LB2-1, 1/40 (— —); MB2-1, 1/1 (— —); and COS interferon-γ, 1/40 (— —).

Figure 4. Response of MM3 cells to IL 3 and MCGF2. Dilutions of supernatants of Con A-induced T cells or COS cells transfected with the cDNA clone for mouse IL 3 were assayed for their effect on the growth of MM3 cells. The assay medium contained no growth factor supplements (Fig. 3A) or 2% (final concentration) Con A-induced LB2-1 cell supernatant as a source of IL 3 (Fig. 3B). Starting dilutions were: MCGF2, 1/4 (— —); COS-IL 3, 1/40 (— —); MB2-1, 1/1 (— —).

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 IL2, 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...
in some cases to remove IL 2. IL 3 was evaluated by combining information from proliferation of NFS60 and MM3 cell lines and HPLC separations (unpublished results). Interferon-γ was evaluated by combining data from the inhibition of NFS60 proliferation, la induction on P388D1 cells, antiviral activity, immune precipitation (see Fig. 8), and inhibition of IgE-enhancing activity (17). B cell stimulating factor 1 (BSF1) activity was evaluated from la induction assays on B cells. IgE 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 Tα2 cells were found to produce IgE- and IgG1-enhancing activities, whereas Tα1 cells were consistently negative in this assay (Table II). Interferon-γ is known to be a potent inhibitor of both enhancing activities (17). Because Tα1 cells produce large amounts of interferon-γ, the absence of these enhancing activities in the Tα1 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 IgE-enhancing activities, may be mediated by the lymphokine BSF1 (18, 20–22). When Tα1 and Tα2 cell supernatants were assayed for the ability to induce la on B cells, Tα2 supernatants were found to contain substantial amounts of this activity, whereas Tα1 cell supernatants did not (Table III). la induction by Tα2 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 Tα1 and Tα2 cell clones were L3T4+ and Lyt-2-. The majority of both types of Tα1 cell clones were also Lyt-1+, although two Tα1 and one Tα2 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.
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 cells specific for alloantigens also recognized determinants that mapped to the I region.

Secreted proteins synthesized by Tn1 and Tn2 cells. Several Tn1 and Tn2 cell lines were labeled with [35S]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 inducible 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 antisemirum 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 antisemirum 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 for 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 immuno-precipitation 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 [R. Aral, 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 lɑ-inducing activity, all of which may be mediated by BSF1 (18, 20–22), a T cell activity that was distinct from IL2, 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
Figure 6. Bioassay of supernatants from antigen-stimulated T cell clones. Three T(1) and two T(2) cell lines were stimulated with antigen in the presence of antigen-presenting cells and the resulting supernatants were assayed on HT2, NSF60, and MM3 cell lines. The MM3 assay medium was supplemented with 2% Con A-induced L92-1 supernatant. All starting dilutions were 1/4. L92-1 (-- --), M013-10 (-- --), M064-37 (-- --), H39-34 (-- --), M064-30 (-- --).

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-γ 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"
TABLE V

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*The alleles for the Aα, Aβ, Aγ, and Eα genes are shown.

*Less than 10 U/ml.

*Not determined.

![Figure 7.](http://www.jimmunol.org/)

Assays, i.e., activities that were not inhibited or obscured by any other activities present in either T1 or T2 supernatants. Such assays include the IL 2 assay on HT2 and the MCGF2 assay on MM3 cells in the presence of saturating amounts of IL 3.

During the course of this study, over a period of 18 mo, the phenotypes of several T1 cell clones have remained constant. T2 cells in general tend to grow slowly, and we have on occasion seen overgrowth of these clones by T1 cells. In some cases, these T1 cell clones were shown by surface markers to have been derived from the feeder cells used to support growth of the T2 clone. We have no evidence for interconversion of T cell clones between T1 and T2 phenotypes. In addition, the properties of the two types of T1 cell clones are consistent from one experiment to another. These findings suggest that the T1 and T2 phenotypes are stable and represent significant functional differences between two sets of T1 cells.

The T cell clones that we have designated T1 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" T1 cells described by Waldmann (3) and Imperiale et al. (4). The clones that we have described as T2 produce BIF-1, which could account for the strong, unlinked B cell helper function provided by the second type of T1 cells described by the same investigators. In addition to their nonspecific B cell help, the second type of T1 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 T1 cell phenotypes may be broader, however, and Melchers et al. (5) and Kim et al. (6) have described results consistent with more than two helper subpopulations. In particular,
The data of Kim et al. (6) when using T cell clones suggest four different phenotypes assessed by the pattern of BI 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 Tn clones that suggest that these may differ in BI cell helper function (manuscript in preparation), and the patterns of biosynthetically labeled secreted proteins suggest additional differences between the Tn cell clones. Although similarities could be seen between all Tn 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 bioassays 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 isolated in one experiment were all Tn2. Both Tn1 and Tn2 clones were found among allotypic Tn 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 IgG 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.2 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 Tn1 cells, whereas CRBC, which induce large IgM but very small IgE responses, may do so by preferentially activating Tn2 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-CRBC T cell lines, which were all Tn1. Only when we examined T cell clones specific for FGG or allantogens 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 Tn 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 must 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 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 2 a real phenomenon, and what determines this selectivity? How is IL-3 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.

Acknowledgments. We thank J. Christiansen, J. Carty, D. Cher, and J. Tomassello for valuable technical assistance, G. Zurawski and K. Arai for generous gifts of recombinant IL-2 and cDNA clones respectively, and J. Zahner and G. Barquet for assistance in preparing the manuscript.

Note Added in Proof: We have recently obtained evidence from serological data3 and recombinant DNA cloning of BSF-16 that the activities described as MCGF2 and TCGF2 are mediated by BSF-1.

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