Innovation, Sciences et Développement économique Canada
Office de la Propriété Intellectuelle du Canada

Innovation, Science and Economic Development Canada
Canadian Intellectual Property Office

CA 2735456 C 2021/11/16

(11)(21) 2 735 456

(12) BREVET CANADIEN
CANADIAN PATENT

(13) C

(86) Date de dépôt PCT/PCT Filing Date: 2009/08/26
(87) Date publication PCT/PCT Publication Date: 2010/03/04
(45) Date de délivrance/Issue Date: 2021/11/16
(85) Entrée phase nationale/National Entry: 2011/02/25
(86) N° demande PCT/PCT Application No.: US 2009/055029
(87) N° publication PCT/PCT Publication No.: 2010/025177
(30) Priorité/Priority: 2008/08/26 (US61/091,915)

(51) Cl.Int./Int.Cl. *C07K 19/00* (2006.01), *A61K 39/00* (2006.01), *A61P 35/00* (2006.01), *A61P 37/02* (2006.01), *C07K 14/54* (2006.01), *C07K 14/705* (2006.01), *C12N 15/62* (2006.01), *C12N 5/10* (2006.01), *A61K 48/00* (2006.01), *C12N 5/0783* (2010.01)

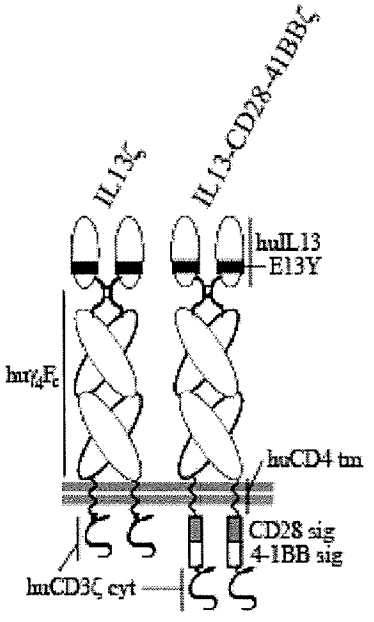
(72) Inventeur/Inventor:
JENSEN, MICHAEL, US

(73) Propriétaire/Owner:
CITY OF HOPE, US

(74) Agent: OSLER, HOSKIN & HARCOURT LLP

(54) Titre : PROCEDE ET COMPOSITIONS POUR FONCTIONNEMENT AMELIORE D'EFFECTEUR ANTITUMORAL DE LYMPHOCYTES T

(54) Title: METHOD AND COMPOSITIONS FOR ENHANCED ANTI-TUMOR EFFECTOR FUNCTIONING OF T CELLS



(57) Abrégé/Abstract:
Integration of costimulatory signaling domains within a tumor targeting chimeric antigen receptor (CAR), such as the IL13Rα2 specific IL13- zetakine (EL13ζ), enhances T cell-mediated responses against tumors even in the absence of expressed ligands for costimulatory receptors.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
4 March 2010 (04.03.2010)

PCT

(10) International Publication Number
WO 2010/025177 A1

(51) International Patent Classification:
C07K 14/435 (2006.01) *A61K 48/00* (2006.01)
C07H 21/00 (2006.01)

(21) International Application Number:
PCT/US2009/055029

(22) International Filing Date:
26 August 2009 (26.08.2009)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/091,915 26 August 2008 (26.08.2008) US

(71) Applicant *(for all designated States except US)*: **CITY OF HOPE** [US/US]; 1500 East Duarte Road, Duarte, CA 91010-0269 (US).

(72) Inventor; and

(75) Inventor/Applicant *(for US only)*: **JENSEN, Michael** [US/US]; 2305 Woodlyn Road, Pasadena, CA 91104 (US).

(74) Agents: **CASSIDY, Martha** et al.; Rothwell, Figg, Ernst & Manbeck, P.C., 1425 K Street, N.W., Suite 800, Washington, DC 20005 (US).

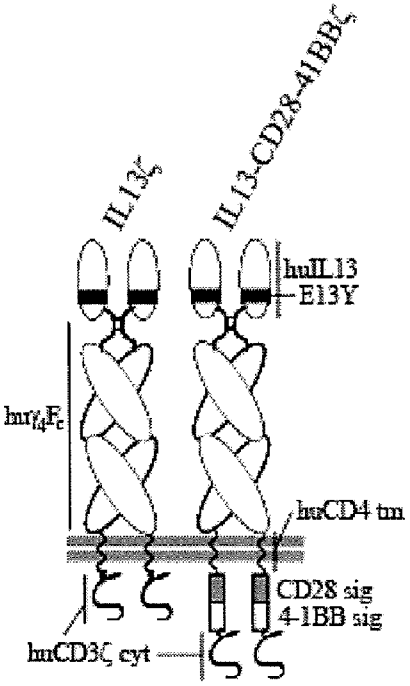
(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM,

[Continued on next page]

(54) Title: METHOD AND COMPOSITIONS FOR ENHANCED ANTI-TUMOR EFFECTOR FUNCTIONING OF T CELLS

FIG. 1



(57) Abstract: Integration of costimulatory signaling domains within a tumor targeting chimeric antigen receptor (CAR), such as the IL13Rα2 specific IL13-zetakine (IL13ζ), enhances T cell-mediated responses against tumors even in the absence of expressed ligands for costimulatory receptors.

WO 2010/025177 A1

TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

— *with sequence listing part of description (Rule 5.2(a))*

Published:

— *with international search report (Art. 21(3))*

Method and Compositions for Enhanced Anti-Tumor Effector Functioning of T cells

BACKGROUND OF THE INVENTION

1. Technical Field

[0002] The invention relates to the field of biomedicine and specifically methods useful for cancer therapy. In particular, embodiments of the invention relate to methods for specific CTL immunotherapeutic strategies for cancer including the use of genetically-modified T lymphocytes expressing chimeric immunoreceptors in the treatment of human brain tumors and other cancers.

2. Description of the Background Art

[0003] Tumor-specific T cell based immunotherapies have been investigated for anti-tumor treatment, however the T cells suffer from the problem of not surviving and remaining active *in vivo* for a long enough period. Often, adoptively transferred T cells do not have the desired potency and duration of tumor cell killing. Therefore, there is a

need in the art for tumor-specific cancer therapies with longer term anti-tumor functioning.

[0004] Cancer-directed immunotherapies traditionally focus on eliciting $CD8^+$ CTL responses. However, stimulation of $CD4^+$ T cell (helper) responses also is important to successful immunotherapy against cancer. $CD4^+$ T cells can influence natural tumor-specific CTL responses directly or indirectly, through conditioning of professional antigen presenting cells via CD40-CD40L, and through the production of cytokines such as IL2 and IFN-γ. The cytocidal effector mechanisms used by $CD4^+$ T cells are mediated either through release of cytokines that activate death receptors on the tumor cell surface, or through direct cell contact where Fas/FasL, TNF-related apoptosis-inducing ligand (TRAIL), or granzyme-perforin dependent pathways mediate tumor cell apoptosis. These helper cells can augment the early clonal expansion and generation of primary $CD8^+$ CTL effectors, and also may affect both the generation and the expansion of functional memory $CD8^+$ T cells.

[0005] Full activation of natural $CD4^+$ T cells requires both an antigen-specific signal through engagement of the T cell receptor/CD3 complex with appropriate peptide/MHC class II complexes and costimulatory signals. These costimulatory signals usually are delivered by ligands that are selectively expressed on specialized antigen presenting cells. T cell costimulation is thought to help maintain tolerance to normal self-antigens expressed by tissues that do not deliver this secondary signal. Because most tumor cells, similar to normal tissues, do not express MHC class II or costimulatory molecules, it stands to reason that they also do not normally promote $CD4^+$ T cell stimulation directly. This theory is supported by several studies that have demonstrated enhanced T cell mediated anti-tumor immunity by vaccination with tumor cells that were transfected with the costimulatory ligand B7-1.

[0006] While altering tumor cell expression of costimulatory molecules is one way to help drive T cell activation, alternative strategies would be very desirable, particularly strategies which involve allowing the T cell to receive and act on costimulatory signals without the need for actual costimulatory ligand(s).

SUMMARY OF THE INVENTION

[0007] Accordingly, embodiments of the present invention provide methods and compositions for enhanced anti-tumor effector functioning of $CD4^+$ and $CD8^+$ T cells for cancer immunotherapy; and specifically to chimeric transmembrane immunoreceptors (termed chimeric antigen receptors or "CARs") which comprise an extracellular domain, a transmembrane region and an intracellular signaling domain. The extracellular domain is made up of a soluble receptor ligand (that is specific for a target tumor antigen or other tumor cell-surface molecule) linked to an optional support region capable of tethering the extracellular domain to a cell surface. The intracellular signaling domain contains the signaling domain from the zeta chain of the human CD3 complex (CD3ζ) and one or more costimulatory signaling domains, such as those from CD28, 4-1BB and OX-40. The extracellular domain contains a recognition element that enables the CAR, when expressed on the surface of a T cell, to direct T cell activity to those cells expressing a receptor or ligand for which this recognition element is specific. For example, a CAR which contains an extracellular domain that contains a recognition element specific for a tumor antigen can direct T cell activity to tumor cells that bear this antigen. The intracellular region enables the T cell to receive costimulatory signals. The costimulatory signaling domains preferably are selected from CD28, 4-1BB, OX-40 or any combination of these. Preferred chimeric receptors comprise a human CD4 transmembrane region, a human IgG_4 Fc and a receptor or ligand that is tumor-specific, such as an IL13 or IL3 molecule. The IL13 molecule may contain the E13Y mutation.

[0008] Embodiments of the invention also provide a method of cancer immunotherapy which comprises administering to a patient in need thereof a receptor such as those described above. Preferred methods targeting IL13Rα2 are useful in treatment of those cancers, including, for example, glioblastoma, breast cancer, head and neck cancer, kidney cancer, ovarian cancer and Kaposi's sarcoma. The methods are useful in treating any accessible tumor that bears an element that specifically binds to the recognition element on the CAR.

[0009] Further embodiments of the invention provide a method of enhancing activity of a chimeric antigen receptor (CAR) against a tumor, which comprises adding CD28, and/or 4-1BB OX-40 signaling domains to the receptor.

[00010] Particular embodiments encompassed by the invention include a tumor-specific chimeric antigen receptor (CAR) which comprises a specific recognition element, an optional support or linker region, a transmembrane region, the signaling domain for CD3 zeta chain and at least one additional costimulatory signaling receptor. Such CARs may include those with two costimulatory signaling receptors, for example those selected from the group consisting of CD28, 4-1BB and OX-40, for example CD28 and 4-1BB.

[00011] The inventive CARs include those wherein the transmembrane region is a human CD4 transmembrane region, a human CD28 transmembrane region, or a human IgG_4 Fc region. Specific recognition elements of the CARs can be an IL13 molecule, an IL3 molecule or the extracellular binding domain of a single chain immunoglobulin that recognizes an antigen selected from the group consisting of Her/2Neu, α3 integrin, CD20, CD19 and EGFRVIII and preferably is an IL13 molecule, most preferably an IL13 molecule that contains the E13Y mutation, such as IL13-CD28-41BBζ.

[00012] Embodiments of the invention also encompass isolated polynucleic acids that encode any of the CARs discussed herein and isolated T lymphocytes that express any of the CARs discussed herein. In addition, embodiments of the invention include methods of cancer immunotherapy which comprises administering to a patient in need thereof such polynucleic acids or T lymphocytes, including as treatments for any of the following cancers: glioblastoma, medulloblastoma, breast cancer, head and neck cancer, kidney cancer, ovarian cancer, Kaposi's sarcoma, acute myelogenous leukemia, and B-lineage malignancies.

[00013] Further embodiments include methods of enhancing activity of a chimeric antigen receptor against a tumor, which comprises adding CD28 and 4-1BB signaling domains to the receptor.

BRIEF DESCRIPTION OF THE DRAWINGS

[00014] Figure 1 is a schematic representation of the IL13ζ and IL13-CD28-41BBζ chimeric antigen receptor (CAR) protein molecules.

[00015] Figure 2 shows the locations of exemplary primers for IL13ζ CAR construction on the native IL13 sequence as indicated. The arrows indicate the position of the primers on the IL13 sequence.

[00016] Figure 3 (given as Figures 3A-3C) provides an exemplary IL13 zetakine-encoding nucleotide sequence (SEQ ID NO:5, upper strand; SEQ ID NO:6, lower strand). The segments of DNA in the sequence include GM-CSFR alpha signal peptide (SEQ ID NO:7), IL13(E13Y) (SEQ ID NO:8), IgG_4(SmP)(SEQ ID NO:9), CD4tm(SEQ ID NO:10) and CD3zeta (SEQ ID NO:11). The complete amino acid sequence is provided as SEQ ID NO:4.

[00017] Figure 4 is a map of the vector IL13zetakine/HyTK-pMG. An exemplary sequence of such a vector is provided in Figure 5.

[00018] Figure 5 (given as Figures 5A-5L) provides the sequence of an exemplary plasmid DNA vector (SEQ ID NO:13, upper strand; SEQ ID NO:14, lower strand). An IL13zetakine amino acid sequence (SEQ ID NO:15) and an HyTk amino acid sequence (SEQ ID NO:16) also are indicated. The segments of DNA which make up the complete sequence include hEF1p (nucleotides 6-549; SEQ ID NO:41), IL13 zetakine (nucleotides 690-2183; SEQ ID NO:42), late sv40pAn (nucleotides 2230-2498; SEQ ID NO:43), Ori ColE1 (nucleotides 2499-3245; SEQ ID NO:44), SpAn (nucleotides 3246-3432; SEQ ID NO:45), hCMV-1Aprom (nucleotides 3433-4075; SEQ ID NO:46), HyTK (nucleotides 4244-6319; SEQ ID NO:47) and BGh pAna (nucleotides 6320-6618; SEQ ID NO:48).

[00019] Figure 6 contains two schematic representations of exemplary CAR linear plasmid constructs. Figure 6A shows a IL13ζ construct and Figure 6B shows a IL13-CD28-41BBζ construct.

[00020] Figure 7 shows western blot analysis of cell lysates derived from mock-, IL13ζ- and IL13-CD28-41BBζ-transfected $CD4^+$ T cells for CAR expression using a mouse anti-human CD3ζ specific mAb.

[00021] Figure 8 is a panel of eight flow cytometry analyses that compare the cell surface phenotype of IL13ζ- and IL13-CD28-41BBζ-expressing bulk $CD4^+$ cells.

[00022] Figure 9 is a panel of six graphs that show flow cytometry results of surface staining of HLA-A2 and HLA-DR (MHC molecules), IL13Rα2 and the costimulatory molecules CD80, CD86, and CD137-L (4-1BBL) (filled histograms) as indicated, compared to isotype controls (open histograms) on U87 glioma target cells.

[00023] Figure 10 is a series of immunoblots showing the results of a kinase assay to determine the kinetics of JNK and p38 (A) and AKT (B) activation, which is measured via phosphorylation of their respective substrates (i.e., P-cJun (phosphorylated c-Jun proto-oncogene), p-GSK3 (phosphorylated glycogen synthase kinase 3) and P-ATF2 (phosphorylated activating transcription factor 2)).

[00024] Figure 11 shows the enhanced Th_1 polarization of IL13-CD28-41BBζ^+ $CD4^+$ T cells in terms of T cell Th_1 cytokine mRNA (Figure 11A) and Th_1 and Th_2 cytokine protein production (Figure 11B).

[00025] Figure 12A provides data showing enhanced cytotoxic activity of IL13-CD28-41BBζ^+ $CD4^+$ T cells (■) against U87 targets compared to that of IL13ζ^+ $CD4^+$ T cells (○) at the indicated E:T ratio in a 4 hour luciferase cytotoxicity assay (LCA). Figure 12B shows similar data for IL13-CD28-41BBζ^+ $CD4^+$ T cells (black bars) and IL13ζ^+ $CD4^+$ T cells (white bars) co-cultured for 48 hours at an E:T ratio of 2:1, and then again co-cultured for an additional 48 hours after addition of fresh targets at the same E:T ratio. Figure 12C provides data obtained with video imaging of T cells expressing the indicated CAR co-cultured with adherent U87 cells, which indicates the number of viable cells per image.

[00026] Figure 13 provides flux data showing sustained anti-tumor effect against established glioblastoma xenografts *in vivo* by IL13-CD28-41BBζ^+ $CD4^+$ T cells. Results observed with IL13ζ- and sham-transfected T cells also are shown.

Date Reçue/Date Received 2020-07-15

[00027] Figure 14 provides the sequence of IL13-IgG_4-cd28tm-CD28gg-Zeta (CO)(SEQ ID NO:36).

[00028] Figure 15 provides the sequence of IL13-IgG_4-cd4tm-CD28-4-1BB-Zeta, also referred to herein as IL13-CD28-41BBζ used/discussed above with respect to the examples below (SEQ ID NO:37). This sequence was used to genetically alter T cells to express the IL13-CD28-41BBζ CAR as described and used in Figures 1, 6, 7, 8, 10, 11, 12 and 13.

[00029] Figure 16 provides the sequence of IL13-IgG_4-cd28tm-CD28-Ox40-Zeta (SEQ ID NO:38).

[00030] Figure 17 provides the sequence of IL13-IgG_4-cd28tm-CD28gg-4-1BB-Zeta (SEQ ID NO:39).

[00031] Figure 18 provides the sequence of IL13-IgG_4-cd28tm-CD28gg^199-4-1BB-Zeta (SEQ ID NO:40).

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[00032] Adoptive immunotherapy using T lymphocytes that express tumor-specific chimeric antigen receptors (CARs) can be a powerful therapeutic strategy for the treatment of cancer. CARs are made up of an extracellular specific recognition element (such as a receptor that binds a tumor antigen) linked via a transmembrane domain to the CD3ζ cytoplasmic signaling domain. These receptors therefore are able both to bind antigen and to transduce T cell activation, independent of MHC restriction. Thus, CARs are "universal" immunoreceptors which can treat a population of patients with antigen-positive tumors irrespective of their HLA genotype.

[00033] According to embodiments of this invention, CARs contain the signaling domain for CD3ζ and the signaling domains of one or more costimulatory receptors that further promote the recycling, survival and/or expansion of adoptively transferred cells expressing the CARs, in addition to specific receptors which allow the cells to engage

targets such as tumors. The signaling domains of the costimulatory receptors are the intracellular portions of each receptor protein that generate the activating signal in the cell. Examples are amino acids 180-220 of the native CD28 molecule and amino acids 214-255 of the native 4-1BB molecule. An especially preferred CAR comprises an extracellular recognition element that is specific for a unique cancer cell surface receptor, is stable in vivo and has low immunogenicity. Derivation from a naturally-occurring soluble cell signal molecule helps to achieve these objectives.

[00034] The term "CAR" refers to a chimeric antigen receptor which is a recombinant biomolecule that contains an extracellular recognition domain, a transmembrane region, and an intracellular signaling domain. The term "antigen," therefore, is not limited to molecules that bind antibodies, but to any molecule that can bind specifically to any receptor. "Antigen" thus refers to the recognition domain of the CAR. The extracellular recognition domain (also referred to as the extracellular domain or simply by the recognition element which it contains) comprises a recognition element that specifically binds to a molecule present on the cell surface of a target cell. The transmembrane region anchors the CAR in the membrane. The intracellular signaling domain comprises the signaling domain from the zeta chain of the human CD3 complex and optionally comprises one or more co-stimulatory signaling domains.

[00035] A CAR that contains the IL13 domain with the E13Y mutation (IL13(E13Y)) and the CD3 zeta chain signalling domain is referred to herein as "IL13ζ." This term includes any chimeric antigen receptor (CAR) that contains an IL13 extracellular recognition domain (a domain that specifically recognizes IL13Rα2 on tumor cells) a transmembrane region, and a CD3 zeta chain intracellular signaling domain. Non-limiting examples of such CARs are provided in Examples 8-12. A CAR that contains IL13(E13Y) and also contains the optional co-stimulatory intracellular domains CD28 and 4-1BB is termed "IL13-CD28-41BBζ" herein.

[00036] Persons of skill will recognize that any nucleotide sequence that encodes IL13(E13Y) would also be suitable for this same purpose. The unmutated sequence of the IL13 signaling domain also is suitable. Any IL13 or IL13(E13Y) encoding sequence including variants with 90%, 95%, 98% or 99% homology to the native sequence may be

used here. Such sequences which are useful for specifically recognizing an IL13 receptor tumor antigen such as IL13Rα2, therefore include those encoded by the native nucleic acid (see Smernov et al., Gene 155:277-281, 1995), the same nucleic acid sequence lacking the E13Y mutation, sequences that are 95%, 98% or 99% homologous to these sequences, longer sequences that comprise those sequences but also include additional nucleotides at the 3' or 5' end, for example any number of additional nucleotides or codons, such as 3, 6, 9, 12 or more nucleotides, or up to about 12, 20, 50 or 100 additional nucleotides, and any sequence that encodes the same amino acid sequence as these nucleic acids due to the degeneracy of the genetic code. In particular, sequences that are codon optimized (CO) for expression by the desired host are contemplated as part of the invention.

[00037] Soluble recognition elements as used in this invention are derived from *de novo* synthesized polypeptides, as described for the IL13 (E13Y) coding sequence in Example 1 or from polypeptides of combinatorial libraries such as phage-display libraries or chemically synthesized libraries. Preferred soluble recognition elements are of human origin and are therefore non-immunogenic, but can be tailored in affinity or specificity through mutagenesis. Upon their expression on T cells, soluble recognition elements are able to bind a target element on the target cell (for example a tumor cell, but not to any appreciable extent on non-target cells), in such a way that results in T cell activation. Thus, the soluble recognition elements that are suitable for this invention have certain advantages over antibody fragments or cell adhesion molecules for target specificity in the inventive CARs, since they are more likely to be stable in the extracellular environment, non-antigenic, and more selective, and therefore are preferred. Examples of suitable soluble receptor elements include autocrine and paracrine growth factors, chemokines, cytokines, hormones, and engineered artificial small molecule ligands that exhibit the required specificity. Natural ligand sequences can be engineered to increase their specificity for a particular target cell. Selection of a recognition element for use in a particular CAR is governed by the nature of the target cell, and the qualities discussed above. In one preferred embodiment of the invention,

the CAR exploits the tumor-restricted expression of IL13Rα2 by malignant glioma, renal cell carcinoma and other tumors by using as the recognition element a mutant of IL13(E13Y) to direct T cells specifically to IL13Rα2-expressing tumor cells. Analogous recognition elements can be created that are specific to any of a variety of cancer cell types that selectively express receptors antigens or any specific molecule on their cell surfaces, for which selective recognition elements are known or can be engineered.

[00038] Examples of suitable support (transmembrane) regions for use with the invention include the constant (Fc) regions of immunoglobins, human CD8α, and artificial linkers that serve to move the targeting moiety away from the cell surface for improved access to and binding on target cells. A preferred support region is the Fc region of an IgG (such as IgG_4). Examples of suitable transmembrane domains include the transmembrane domains of the leukocyte CD markers, preferably that of CD4 or CD28. Examples of intracellular receptor signaling domains include the T cell antigen receptor complex, preferably the zeta chain of CD3, however any transmembrane region sufficient to anchor the CAR in the membrane can be used. Persons of skill are aware of numerous transmembrane regions and the structural elements (such as lipophilic amino acid regions) that produce transmembrane domains in numerous membrane proteins and therefore can substitute any convenient sequence. T cell costimulatory signaling receptors suitable for improving the function and activity of CAR-expressing cells include, but are not limited to, CD28 and 4-1BB also known as (CD137), and OX-40.

[00039] Signaling via CD28 is required for IL2 production and proliferation, but does not play a primary role in sustaining T cell function and activity. 4-1BB (a tumor necrosis factor-receptor family member expressed following CD28 activation) and OX-40 are involved in driving long-term survival of T cells, and accumulation of T cells. The ligands for these receptors typically are expressed on professional antigen presenting cells such as dendritic cells and activated macrophages, but not on tumor cells. Expressing a CAR that incorporates CD28 and/or 4-1BB signaling domains in $CD4^+$ T cells enhances the activity and anti-tumor potency of those cells compared to those

expressing a CAR that contains only the CD3ζ signaling domain. Preferably, the inventive CARs contain both CD28 and 4-1BB signaling domains.

[00040] In order for the CAR to target tumor cells, they contain an extracellular binding molecule that binds a tumor surface marker and preferably specifically binds to a unique tumor surface molecule. Some cancers express or overexpress molecules of the immune system. Gliomas, for example, express IL13 receptors, and in particular, high-affinity IL13 receptors. However, unlike the IL13 receptor trimolecular complex used by the immune system, (which consists of the IL13Rα1, the IL4Rβ, and γc), glioma cells overexpress a unique IL13Rα2 chain capable of binding IL13 independently of the requirement for IL4Rβ or γc44. Like its homolog IL4, IL13 has pleotropic immunoregulatory activity outside the CNS. Both IL13 and IL4 stimulate IgE production by B lymphocytes and suppress pro-inflammatory cytokine production by macrophages.

[00041] Detailed studies using autoradiography with radiolabeled IL13 have demonstrated abundant IL13 binding on nearly all malignant glioma tissues studied. This binding is highly homogeneous within tumor sections and in single cell analysis. However, molecular probe analysis specific for IL13Rα2 mRNA did not detect expression of the glioma-specific receptor by normal brain elements and autoradiography with radiolabeled IL13 also could not detect specific IL13 binding in the normal CNS. These studies suggest that the shared IL13Rα1/IL4β/γc receptor is not expressed detectably in the normal CNS. Therefore, IL13Rα2 is a very specific cell-surface target for glioma and is a highly suitable target for this invention. Persons of skill are aware of other suitable targets for CARs, which are expressed or overexpressed on the cells to be targeted and preferably are not expressed, or are expressed to a much lesser degree, on other cells. Another example of a tumor-specific target suitable for targeting with CARs of this invention is IL3 receptor (IL3R; e.g., expressed on acute myeloid leukemia (AML) cells.

[00042] Binding of IL13-based cytotoxins to the broadly expressed IL13Rα1/IL4β/γc receptor complex, however, has the potential of mediating undesired toxicities to normal tissues outside the CNS, and thus limits the systemic administration of these agents. An amino acid substitution in the IL13 alpha helix A at amino acid 13 of

tyrosine for the native glutamic acid selectively reduces the affinity of IL13 to the IL13Rα1/IL4β/γc receptor. Binding of this mutant (termed IL13(E13Y) to IL13Rα2, however, was increased relative to wild-type IL13 by 50-fold. Thus, this minimally altered IL13 analog simultaneously increases IL13's specificity and affinity for glioma cells. Therefore, a preferred embodiment of the invention employs an IL13 containing a mutation at amino acid 13. IL13 having the natural sequence also may be used with the invention, however, and can be useful, particularly in situations where the modified T cells are to be locally administered, such as by injection directly into a tumor mass.

[00043] A preferred type of CAR for specifically targeting tumors that express IL13Rα2 is made up of an extracellular IL13-mutant cytokine in which the IL13 protein contains a substitution of tyrosine for the naturally-occurring glutamic acid at amino acid 13 of the protein (termed IL13(E13Y) here), connected to a human IgG_4 hinge-Fc domain support region which is fused to a CD4 transmembrane domain and a cytoplasmic CD3ζ signaling sequence. See Figure 1, left side. This CAR is referred to herein as an "IL13ζ CAR". When this CAR also contains the CD28 and 4-1BB signaling domains, it is referred to as IL13-CD28-41BBζ. See Figure 1, right side.

[00044] An immunoreceptor according to the present invention can be produced by any means known in the art, though preferably it is produced using recombinant DNA techniques. Nucleic acids encoding the several regions of the chimeric receptor can be prepared and assembled into a complete coding sequence by standard techniques of molecular cloning known in the art (genomic library screening, PCR, primer-assisted ligation, site-directed mutagenesis, etc.) as is convenient. The resulting coding region is preferably inserted into an expression vector and used to transform a suitable expression host cell line, preferably a T lymphocyte cell line, and most preferably an autologous T lymphocyte cell line.

[00045] Briefly, an IL13ζ CAR may be constructed using known methods as follows. The IL13 mutant DNA IL13(E13Y) can be synthesized by PCR with primers based on the known IL13 mRNA sequence. The complete IL13 gene sequence is reported in Smemov et al., "Tandem arrangement of human genes for interleukin-4 and interleukin-13: resemblance in their organization." Gene 155:277-281, 1995.

De novo synthesis of the
IL13(E13Y) was performed using forward primer IL13P1 and four reverse primers, IL13P2, IL13P3, IL13P4, and IL13P5, shown in Table I, below, and Figure 2. This IL13 mutant sequence then can be modified to contain a 5' leader sequence, if desired. A transmembrane anchor such as the human IgG_4-CD4 transmembrane (IgG_4-CD4tm) and CD3 zetachain (CD3ζ) cytoplasmic sequences also can be added to the 3' end by PCR fusion techniques or any convenient method. The complete IL13ζ sequence is given in Figure 3 as an example of the invention. The same methods can be used to construct equivalent molecules using different recognition elements. The final construct then can be ligated into any suitable plasmid expression vector. A preferred plasmid expression vector is pMG (available from Invivogen™).

[00046] The IL13(E13Y)-containing CAR specifically directs T cells to target IL13 receptor α2 (termed IL13Rα2 here)-expressing glioma cells, renal carcinoma cells and cells of any cancer expressing IL13Rα2 in an MHC-independent manner. Anti-tumor $CD4^+$ T cell effectors were generated to be re-directed to recognize tumor cells using a CAR containing the signaling domains derived from CD3-ζ, CD28 and 4-1BB. Either the IL13ζ or IL13-CD28-41BBζ CAR was transfected into human primary T cells using a non-viral plasmid vector (pEK) and electroporation methods (Nucleofector Technology™ of Amaxa Biosystems™, Gaithersburg, MD). $CD4^+$ T cells expressing either CAR (IL13ζ or IL13-CD28-41BBζ) were compared for their potential to activate effector-associated signaling pathways, produce cytokines, lyse target cells and control *in vivo* tumor growth. The results showed that addition of the CD28 and 4-1BB signaling domains to IL13ζ enhances the anti-tumor effector functions of $CD4^+$ T cells expressing the CAR. Effector T cells expressing the IL13-CD28-41BBζ immunoreceptor were able to mediate costimulatory signals through JNK, p38 and AKT kinases in the tumor environment where costimulation would be expected to be limiting. The enforced costimulation in the human primary $CD4^+$ T cells supports the polarization of these cells to a Th_1 phenotype in a manner that is associated with sustained anti-tumor efficacy both *in vitro* and *in vivo*. Effector signals downstream of the CAR in $CD4^+$ T cells were demonstrated. These

effector signals correlated with the observed Th_1 bias and the prolonged anti-tumor effector activity of these cells both *in vitro* and *in vivo*.

[00047] CD3ζ signaling alone drives ERK activation. This correlates well with the finding here that ERK activity is not enhanced in IL13-CD28-41BBζ-expressing cells compared to IL13ζ-expressing controls (both CARs contain the CD3ζ signaling domain). Costimulation of CD3 with CD28 drives activation of JNK and p38; 4-1BB-mediated co-stimulation of CD3 also involves JNK activation. Both JNK and p38 play primary roles in driving Th_1-polarized immune responses by $CD4^+$ T cells, including their production of IL2, IFN-γ and TNF-α. The activation of AKT kinase, another downstream signaling component of both CD28 and 4-1BB, also is involved in up-regulation of IL2 and INF-γ, but not Th_2 cytokines. The association of a pronounced Th_1 phenotype (see examples, below) with enhanced JNK and p38 MAP kinase induction and sustained ATK activation (see examples, below) in IL13-CD28-41BBζ -expressing T cells strongly indicates that the CD28 and 4-1BB signaling moieties work with the CD3ζ signaling domain in this chimeric receptor to retain the capacity to transduce the downstream signaling pathways normally associated with these costimulatory receptors. Regardless of how strong the activated Th_1 phenotype driven by costimulatory domain signals may be, retention and recycling of functional anti-tumor effector $CD4^+$ T cells within the tumor microenvironment greatly assists in achieving anti-tumor potency.

[00048] Compared to CD3ζ-mediated activation alone, CD4+ effector T cells expressing the IL13-CD28-41BBζ CAR exhibited augmented/sustained MAPK and AKT activity, upregulated Th_1 cytokine production, and enhanced cytolytic potency against tumor targets. Moreover, upon recursive stimulation with tumor, the IL13-CD28-41BBζ^+ $CD4^+$ cells retained/recycled their lytic function whereas IL13ζ^+ $CD4^+$ cells were effective, but sooner became anergic/exhausted. These in vitro observations correlated with enhanced in vivo control of established orthotopic CNS glioma xenografts in immunodeficient mice mediated by adoptively transferred ex vivo expanded $CD4^+$ T cells expressing the costimulatory CAR. These studies therefore demonstrate the effect of integrating costimulation with CD3ζ signaling events to fully activate $CD4^+$ anti-tumor effector cells for sustained function in the tumor microenvironment.

[00049] CD28 and 4-1BB costimulatory signals mediated via AKT can inhibit activation-induced cell death through up-regulation of anti-apoptotic proteins. The enhanced AKT activation seen in the IL13-CD28-41BBζ-expressing T cells was associated with enhanced recycling of tumor specific activity *in vitro* as well as prolonged tumor growth control *in vivo*. Thus, the costimulatory CAR can enhance the duration and/or retention of anti-tumor activity in a manner that can significantly improve the clinical efficacy of adoptive therapy protocols.

[00050] Tumor-specific CARs that contain their own costimulatory signaling domains provide a new approach for activating T lymphocytes against a wider variety of solid tumors that do not express these costimulatory ligands. IL13Rα2, for example, has been identified as an over-expressed cell-surface target on various human tumors, including breast cancer, head and neck cancer, kidney cancer, ovarian cancer and Kaposi's sarcoma as well as gliomas. Thus, T cells expressing a CAR that contains an IL13 zetakine and CD28 and 4-1BB can be used to treat glioblastomas (glioma) and any cancer, such as those listed above, that have the IL13 target on their surface.

[00051] The invention specifically contemplates CARs that contain CD3ζ, CD28 and 4-1BB (and/or other costimulatory signaling domains) which can be directed to any tumor by incorporating a moiety that binds to a cell-surface-expressed tumor target, for example an antigen. Examples of other tumor-specific target binders include Her2/Neu (ErbB-2), α3 integrin, CD20, CD19, EGFRVIII, IL3Rα (CD123), LEA, CD44v6 or any target specific to a tumor, preferably a solid tumor that does not express the costimulatory signaling domain which is contained on the CAR. Therefore, constructs for targeting human tumors in this manner can include those with specificities for Her2/Neu (ErbB-2), α3 integrin, CD20, CD19, EGFRVIII, IL3Rα (CD123), LEA, CD44v6 or any specific tumor antigen or other cell-surface component accessible to binding by a chimeric T cell receptor. Persons of skill are aware of these specific tumor antigens and receptors which can be exploited to target a specific tumor, and are aware of the tumors that can be targeted in this manner.

[00052] Both $CD4^+$ and $CD8^+$ T cell effector functions can be triggered via these receptors, therefore both of these T cell types are contemplated for use with the

invention. $CD8^+$ T cells expressing the IL13 CARs of this invention may be used to lyse target cells and to produce IL2 in the presence of target cells, among the other functions of these cells. Expression of the appropriate costimulatory CAR in either or both $CD4^+$ and $CD8^+$ T cells would be used to provide the most effective population of cells for adoptive immunotherapy, consisting therefore of either or both professional helper and killer T cells that exhibit enhanced and/or long term viability and anti-tumor activity.

[00053] The following examples are solely for the purpose of illustrating one embodiment of the invention.

EXAMPLES

Example 1. Transfection and Expression of IL13Rα2-specific Chimeric Receptors in Primary Human T Lymphocytes.

[00054] To engage both T cell receptor (TCR)- and costimulatory-like signaling cascades upon interaction with glioma tumor antigen IL13Rα2, signaling elements derived from CD28 and 4-1BB were integrated into an IL13-zetakine (IL13ζ) chimeric antigen receptor (CAR). The preferred IL13ζ CAR is composed of the extracellular IL13(E13Y) mutein, human IgG_4 hinge-Fc linked to the human cytoplasmic CD3ζ via the transmembrane domain of human CD4. See Figure 1. De novo synthesis of the IL13(E13Y) coding sequence was performed using primers IL13P1, IL13P2, IL13P3, IL13P4, and IL13P5. See Table I, below, and Figure 2. The final sequence (417bp) was end-digested with EcoRI-BamHI, and ligated into the plasmid pSK (Stratagene™) as ligation 312#3. Ligation 312#3 was mutagenized (Stratagene™ kit, per manufacturer's instructions) to repair a deleted nucleotide using the primers IL13 312#3 mut5-3 and IL13 312#3 mut3-5 and ligation 312#3 as a template, to form ligation 348#1 (IL13ζ/pSK).

[00055] The human GM-CSFR alpha chain signal peptide (hsp) coding sequence was fused to the 5' end of IL13(E13Y) by standard PCR splice overlap extension. The

hsp sequence was obtained from the template ligation 301#10 (hsp/pSK) using primers 5':19hsp5' and 3': hsp-IL13FR. See Table I. The IL13 sequence was obtained using the primers 5': hsp-IL13FF and 3': IL13-IgG4FR, and ligation 312#3 as template. See Table I.

[00056] A sequence encoding the IgG4 Fc, CD4 transmembrane and CD3ζ cytoplasmic regions (IgG4m:zeta; nucleotides 421-1512 of the complete IL13ζ sequence of Figure 3 (SEQ ID NO:12)) was fused to the 3' end of the human signal peptide-IL13 fusion sequence using the same methods. The IgG4m:zeta sequence was obtained using the primers 5': IL13-IgG4FF and 3': ZetaN3' (see Table 1), using the sequence R9.10 (IgG4mZeta/pSK) as template. The 1119 bp IgG4m:zeta sequence was fused to the hsp-IL13 fusion sequence using the respective sequences as templates, and the primers 5': 19hsp5' and 3': ZetaN3' (see Table 1), to yield a 1522 bp hsp-IL13-IgG4m:zeta fusion sequence. The ends were digested with XbaI-NotI, and ligated into pSK as ligation 351#7, to create the plasmid IL13ζ/pSK (4464 bp) (i.e. the IL13ζ sequence of Figure 3 , within pSK cloning vector.

[00057] An expression vector containing the IL13ζ coding sequence was created by digesting IL13ζ/pSK with XbaI-NotI, and creating blunt ends with Klenow, and ligating the resulting fragment into the plasmid pMG^Pac (Invitrogen™) (first prepared by opening with SgrAI, blunting with Klenow, and dephosphorylation with SAP), to yield the plasmid IL13ζ/pMG. The hygromycin resistance region of IL13ζ/pMG was removed by digestion with NotI-NheI, and replaced by the selection/suicide fusion HyTK, obtained from plasmid CE7R/HyTK-pMG by digestion with NotI-NheI, to create the expression vector IL13ζ/HyTK-pMG (6785 bp). This plasmid comprises the human elongation factor-1α promoter (hEF1p) at bases 6-549, the IL13ζ coding sequence at bases 690-2183, the Simian Virus 40 Late polyadenylation signal (Late SV40pAN) at bases 2230-2498, a minimal E. coli origin of replication (Ori ColE1) at bases 2499-3245, a synthetic poly A and Pause site (SpAN) at bases 3246-3432, the Immediate-early CMV enhancer/promoter (h CMV-1Aprom) at bases 3453-4075, the Hygromycin resistance-Thymidine kinase coding region fusion (HyTK) at bases 4244-6319, and the bovine growth hormone polyadenylation signal and a transcription pause (BGh pAn) at bases

6320-6618. The plasmid has a PacI linearization site at bases 3233-3240. The hEF1p, late SV40pAN, ori ColE1, SpAn, and hCMV-1Aprom elements all were derived from the parent plasmid pMG^Pac. In sum, IL13ζ/HyTK-pMG is a modified pMG backbone, expressing the IL13ζ gene from the hEF1 promoter, and the HyTK fusion from the hCMV-1A promoter. A map of the plasmid IL13ζ/HyTK-pMG appears in Figure 4. The full nucleic acid sequence of the plasmid is shown in Figures 5A-5L (SEQ ID NOs:13 and 14. The sequence of the IL13ζ insert also is given in Figure 3 (SEQ ID NOs:5 and 6).

[00058] Assessment of the integrity of the expressed construct was confirmed by western blot using the anti-human CD3ζ monoclonal antibody clone 8D3 (BD PharMingen™, San Diego, CA) to probe whole cell lysates derived from Jurkat T cell stable transfectants cocultured in the presence or absence of tunicamycin, an inhibitor of glycosylation. Jurkat T cell stable transfectants (Jurkat-IL13-pMG bulk line) were obtained by electroporating Jurkat T cells with the IL13ζ/HyTK-pMG expression vector, followed by selection and expansion of positive transfectants. $2x10^6$ cells from the Jurkat-IL13-pMG bulk line were plated per well in a 24-well plate with or without 5 µg/mL, 10 µg/mL, or 20 µg/mL Tunicamycin. The plate was incubated at 37°C for 22 hours. Cells were harvested from each well, and each sample was washed with PBS and resuspended in 50 µL RIPA buffer (PBS, 1% NP40, 0.5% sodium deoxycholate, 0.1% SDS) containing protease inhibitor (1 tablet/10 mL Complete Protease Inhibitor Cocktail). Samples were incubated on ice for one hour, before being centrifuged at 4°C for 20 minutes at 14,000 rpm. Samples of centrifuged lysate supernatant were harvested and boiled in a 1:3 volume of sample buffer under reducing conditions, then subjected to SDS-PAGE electrophoresis on a 12% acrylamide gel. Following transfer to nitrocellulose, the membrane then was blocked in a Blotto™ solution containing 4% non-fat dried milk in T-TBS (0.1% Tween 20™ in Tris buffered saline pH 8.0) for 1 hour. Membrane was then incubated with the primary mouse anti-human CD3ζ monoclonal antibody at a concentration of 0.5 µg/mL for one hour, washed, and then incubated with a 1:3000 dilution (in Blotto™ solution) of goat anti-mouse IgG alkaline phosphatase conjugated secondary antibody (Bio-Rad™ ImmunoStar™ Kit) for 1 hour. Prior to

developing, the membrane was washed 4 additional times in T-TBS, and then incubated with 3 mL phosphatase substrate solution (Bio-Rad™ ImmunoStar™ Kit) for 5 minutes at room temperature. The membrane was then covered with a plastic development folder (Tropix™) and exposed to X-ray film. Consistent with the known glycosylation pattern of wild-type human IL13, the electrophoretic mobility of the expressed IL13(E13Y) zetakine indicates a heavily glycosylated protein which, when expressed in the presence of tunicamycin, is reduced to an amino acid backbone of approximately 54 kDa.

[00059] Construction of the co-stimulatory CAR was initiated with an HyTK-2A-IL13ζ-pcDNA3.1(+) construct, which encodes the selection/suicide fusion gene HyTK, the *de novo* synthesized self-cleavable foot-and-mouth disease 2A peptide (TCTAGAGGAGCATGCCAGCTGTTGAATTTTGACCTTCTTAAGCTTGCGGGAGACGT CGAGTCCAACCCTGGGCCC; SEQ ID NO: 49), and the IL13ζ, molecule (Figure 3), cloned into pcDNA3.1(+) (Invitrogen™). To confer resistance to methotrexate (MTX), the HyTK gene was replaced by PCR with an dihydrofolate reductase (DHFR) gene (amplified from a cDNA library derived from peripheral blood mononuclear cells (PBMC) that had been stimulated for three days with the OKT3 antibody which recognizes the CD3 chain of the T cell receptor which contained L22F and F33S mutations generated using a QuikChange™ Site-Directed Mutagenesis Kit (Stratagene™). The resulting DHFRdm-2A-IL13ζ construct was then excised with NheI and NotI, eluted and ligated into the similarly digested mammalian plasmid expression vector pEK. The pEK vector had been modified originally from pcDNA3.1(+) by removing the CMV promoter and the ampicillin gene and replacing them with the human Elongation Factor 1α promoter (EF1p) gene derived from pMG (Invivogen™) to create the plasmid DHFRdm-2A-IL13ζ_pEK (pJ01275-9). CD28 cDNA was purchased from Invitrogen™ and 4-1BB coding region was amplified by PCR from a cDNA library derived from peripheral blood mononuclear cells (PBMC) that had been stimulated for three days with the OKT3 antibody (using primers 41BB5' and 41BB3', see Table 1).

[00060] The intracellular signaling regions of CD28 and 4-1BB (amino acids 180-220 and 214-255, respectively, of the native CD28 and 4-1BB sequences) were fused by PCR (using the primers CD4-CD28F, CD28-4-1-BBR, CD28-4-1bbF, and 41bb93

provided in Table I) into the junction between the CD4 transmembrane and cytoplasmic CD3ζ (amino acids 52-164 of native CD3ζ) regions. See Figure 6, which provides schematic representations of examples of IL13ζ (Figure 6A) and IL13-CD28-41BBζ (Figure 6B) linear plasmid constructs. The placement of human IL13 mutein (E13Y), human IgG_4 hinge-Fc (IgG_4), human CD4 transmembrane (tm), human CD3ζ cytoplasmic (Zeta), CD28 cytoplasmic (28c) and 4-1BB cytoplasmic (BBc) segments are indicated in Figure 6. Restriction enzyme sites that were used to insert the different PCR fragments also are indicated in Figure 6 (*Nhe*I, *Kpn*I, *Nsi*I, *Not*I), with their predicted base pair locations provided in parentheses. As shown in Figure 6A, the CAR, IL13-CD28-41BBζ, comprises the cytoplasmic domain of CD28 and 4-1BB fused to that of CD3ζ. Each construct shown in Figure 6A has a huIL13 domain containing the E13Y mutation which makes it IL13Rα2-specific, a human IgG_4 hinge-Fc domain ($huγ_4Fc$), a human CD4 transmembrane (huCD4tm) domain, and a human CD3ζ cytoplasmic (huCD3ζ cyt) domain; the IL13-CD28-41BBζ CAR has the signaling (sig) domains of CD28 and 4-1BB inserted between the CD4 transmembrane and CD3ζ cytoplasmic domains. The PCR primers used in construction of the plasmids and used in expression analysis are provided in Table I.

[00061] Bulk cultures of $CD4^+$ T cells obtained by MACS™ separation using the manufacturer's protocol (Miltenyi Biotec™ Inc.) were maintained in RPMI media with 10% FCS, 1% L-glutamine, 2.5% HEPES buffer, 50 U/mL rhIL2, 10ng/mL rhIL15 and 0.1 μM MTX. Isolation, activation, and electroporation of human T cells was performed as follows. PBMC were isolated by density gradient centrifugation over Ficoll-Paque (Pharmacia Biotech™) of heparinized peripheral blood obtained from consenting healthy donors. The cells were resuspended in nucleofection solution using the Amaxa™ Human T cell Nucleofector kit (Amaxa™ Inc.). Plasmid (1 μg/$5x10^6$ cells) was added, and cells were electroporated using the Amaxa™ Nucleofector I (Amaxa™ Inc.), program U-14. Cells then were harvested in phenol red-free medium with 10% FCS, allowed to rest overnight, and then stimulated with 30 ng/mL OKT3 and 5ng/mL rhIL15 in RPMI with 10% FCS for three days. Successful transfectants were selected using media containing 0.1 μM MTX and 5ng/mL rhIL15.

[00062] The expression of CARs was assessed by immunoblotting analysis with an antibody specific to CD3ζ. Whole cell lysates of bulk MTX-selected $CD4^+$ T cells (mock-, IL13ζ- and IL13-CD28-41BBζ-transfected) were tested for the CAR expression (chimeric CD3ζ) using known methods and a commercially available mouse anti-human CD3ζ-specific monoclonal antibody, 1D3. As expected with such highly glycosylated proteins, multiple bands within the expected molecular weights were observed. See Figure 7.

[00063] The levels of IL13ζ or IL13-CD28-41BBζ CAR expressed on the surface of $CD4^+$ T cells were examined by detection of membrane-bound IL13 using flow cytometry. See Figure 8. PBMC transfected with cDNA encoding IL13ζ or IL13-CD28-41BBζ CAR were propagated for an average of 10 weeks under selective concentrations of MTX (0.1 μM), magnetically sorted for $CD4^+$ cells by MACS™ separation, and examined for surface expression of IL13-containing CAR (Y-axes), and CD4, CD8, TCRα/β, or CD28 (X-axes) as indicated. Isotype-matched fluorescent mAbs were used to establish the quadrants. These genetically modified T cell populations were not only predominantly $CD4^+$ and $CD8^-$, as expected after magnetic bead based MACS™ purification of $CD4^+$ cells, but also expressed high and equivalent levels of endogenous TCR and low to undetectable levels of costimulatory CD28. See Figure 8.

[00064] The IL13Rα2^+ human glioblastoma tumor cell target line used in these studies, U87, also was phenotyped to confirm that those cells express MHC class I and class II on their surface and do not express the costimulatory ligands CD80/86 or 4-1BBL. See Figure 9, which shows the surface staining of MHC molecules HLA-A2 and HLA-DR, IL13R and costimulatory molecules CD80, CD86, and CD137-L (4-1BBL) (filled histograms) as indicated, compared to isotype controls (open histograms) on U87 glioma target cells, as analyzed by flow cytometry.

[00065] Flow cytometric analysis involved evaluating the cell-surface expression of the IL13-CAR constructs by staining with PE-conjugated or FITC-conjugated anti-human IL13 monoclonal antibodies (BD PharMingen™). The cell-surface phenotype of primary human T cell transfectants was assayed with FITC-conjugated anti-CD4, anti-CD8, and anti-TCR α/β antibodies or with PE-conjugated anti-CD28 antibodies (BD PharMingen™). The cell-surface phenotype of human U87 glioma cells was assayed

with FITC-conjugated anti-HLA-A2, anti-HLA-DR, and anti-CD80 antibodies, or with PE-conjugated anti-CD86 and anti-CD137-L (4-1BBL) antibodies, compared to FITC- and PE-conjugated isotype controls (BD PharMingen™). IL13Rα2 expression was assayed using goat anti-human IL13Rα2 (R&D Systems™) followed by FITC-conjugated mouse anti-goat IgG (Jackson ImmunoResearch™).

Table I. PCR primers for CAR Construction.

Primer Name	Primer Sequence (5'-3')	SEQ ID NO:
IL3P1	TATGAATTCATGGCGCTTTTGTTGACCACGGTCATTGCTCTCACTTGC CTTGGCGGCTTTGCCTCCCCAGGCCCTGTGCCTCCCTCTACAGCCC TCAGGTAC	17
IL3P2	GTTGATGCTCCATACCATGCTGCCATTGCAGAGCGGAGCCTTCTGGT TCTGGGTGATGTTGACCAGCTCCTCAATGAGGTACCTGAGGGCTGTA GAGGGAG	18
IL3P3	CTCTGGGTCTTCTCGATGGCACTGCAGCCTGACACGTTGATCAGGG ATTCCAGGGCTGCACAGTACATGCCAGCTGTCAGGTTGATGCTCCAT ACCATGC	19
IL3P4	CCTCGATTTTGGTGTCTCGGACATGCAAGCTGGAAAACTGCCCAGCT GAGACCTTGTGCGGGCAGAATCCGCTCAGCATCCTCTGGGTCTTCT CGATGGC	20
IL3P5	TCGGATCCTCAGTTGAACCGTCCCTCGCGAAAAAGTTTCTTTAAATGT AAGAGCAGGTCCTTTACAAACTGGGCCACCTCGATTTTGGTGTCTCG G	21
IL13 312#3 mut5-3	CAACCTGACAGCTGGCATGTACTGTGCAGCCCTGGAATC	22
IL13 312#3 mut3-5	GTTGGACTGTCGACCGTACATGACACGTCGGGACCTTAG	23
5':19hsp5'	ATCTCTAGAGCCGCCACCATGCTTCTCCTGGTGACAAGCCTTC	24
3': hsp-IL13FR	GAGGGAGGCACAGGGCCTGGGATCAGGAGGAATG	25
5': hsp-IL13FF	CATTCCTCCTGATCCCAGGCCCTGTGCCTCCCTC	26
3': IL13-IgG4FR	GGGACCATATTTGGACTCGTTGAACCGTCCCTCGC	27
5': IL13-IgG4FF	GCGAGGGACGGTTCAACGAGTCCAAATATGGTCCC	28
3': ZetaN3'	ATGCGGCCGCTCAGCGAGGGGGCAGG	29
41BB5'	ATCGAATTCGCCGCCACCATGGGAAACAGCTGTTACAAC	30
41BB3'	GATAAGCTTATCGATTCACCACATCCTCCTTCAGTT	31
CD4-CD28F	CATTGGGCTAGGCATCTTCTTCAGGAGTAAGAGGAGCAGGCTC	32
CD28-4-1BBR	GTTTCTTTCTGCCCCGTTTGCCACCTCCGGAGCGATAGGCTGCGAA G	33
CD28-4-1BBF	CTTCGCAGCCTATCGCTCCGGAGGTGGCAAACGGGGCAGAAAGAAA C	34
4-1BB93'	GTTGCGGCCGCTCACAGTTCACATCCTCCTTCTTCTTC	35

Example 2. Potentiation of JNK and p38 MAPK Signaling with Sustained AKT Signaling by IL13-CD28-41BBζ.

[00066] T cells stimulated by the engagement of the TCR-CD3 complex along with the auxiliary receptors CD28 or 4-1BB are known to drive signals through AKT as well as the mitogen-activated protein kinases (MAPKs). To investigate the ability of costimulatory CARs to influence these downstream effector pathways, *in vitro* kinase assays were used to evaluate and compare the activity of AKT and MAPK family members ERK, JNK and p38 in IL13ζ- and IL13-CD28-41BBζ-expressing $CD4^+$ T cells following engagement of U87 target cells. Human glioma line, U87, was obtained from ATCC (Rockville, MD). All tumor lines are adherent, and were grown in DMEM (Irvine Scientific™) supplemented with 10% heat-inactivated FCS, 25 mM HEPES, and 2 mM L-glutamine. $CD4^+$ T cells expressing IL13ζ or IL13-CD28-41BBζ CAR were incubated with U87 glioma cells for the times indicated in Figure 10 prior to assay.

[00067] After IL13ζ- or IL13-CD28-41BBζ-expressing CD4+ T cells were stimulated with tumor target cells for up to 48 hours (Figure 10A) or 72 hours (Figure 10B), levels of the JNK, p38 and AKT total protein substrates (i.e., cJun, ATF2, and GSK3, respectively) and the phosphorylated substrates (P-cJun, P-ATF2, and P-GSK3, respectively) were measured by Western immunoblot. The fold increase in the phosphorylation of each substrate, as a measure of kinase activity, is indicated at the bottom of each group in Figure 10.

[00068] A non-radioactive solid-state kinase assay was performed using a method modified from Hibi et al., "Identification of an oncoprotein- and UV-responsive protein kinase that binds and potentiates the c-Jun activation domain." Genes Dev. 7:2135-2148, 1993. Using T cell lysates that had been separated from target cells by gentle centrifugation (1000 rpm, < 3 minutes), the selected kinase was immunoprecipitated overnight at 4°C using antibodies specific to ERK1/2, JNK, p38, and AKT (Cell Signaling Technology Inc.™). The immunoprecipitated complexes were washed in lysis buffer (PBS with 1% NP40, 0.1% SDS, and 0.5% sodium deoxycholate) and kinase buffer (25 mM Tris, pH 7.5, containing 10 mM $MgCl_2$ and 2 mM EGTA), and the assay was

performed at 30°C for 30 minutes, using 1 µg of substrate in the presence of 10 µM ATP.

[00069] Glutathione *S* transferase (GST) fusion proteins: GST-ELK, GST-ATF2 and GST-GSK3β (Cell Signaling Technology™ Inc.), and GST-cJun(1–79) (as described in Chang et al., Cell 124:601-613, 2006) were used as the substrates for the ERK, p38, AKT, and JNK kinase assays, respectively. The resulting products were resolved in 12% NuPAGE™ (Invitrogen™) according to standard methods and transferred to nitrocellulose membrane using the Xcell II Blot Module™ (Invitrogen™). The blots were probed with antibodies to phospho-ELK, ATF2, cJun and GSK3β (Cell Signaling Technology™ Inc.) to detect phosphorylated GST fusion proteins and antibodies to GST (BD PharMingen™) to detect the total amount of substrate. The immunoblots then were incubated with IRDye 680-conjugated rabbit or IRDye800-conjugated mouse immunoglobulin-specific antibodies (LI-COR™). Blocking buffer (purchased from LI-COR™) was used to pretreat blots and for antibody dilution. The blots were viewed and recorded using an Odyssey™ Infrared Imaging System (LI-COR™) and band intensities were quantitated using Odyssey™ v2.0 software (LI-COR™). Phosphorylation of substrate, a measure of kinase activity, was quantitated and normalized to corresponding detected amounts of immunoprecipitated kinase and total kinase substrate. Relative kinase activity of IL13ζ$^+$ CD4$^+$ T cells at t = 0 was given an arbitrary value of 1.0; dashes (-) indicate fold differences < 1.0 (see Figure 10).

[00070] The kinase assay was able to detect enhanced JNK and p38 MAPK activity and prolonged AKT kinase activity in IL13-CD28-41BBζ$^+$ CD4$^+$ T cells after co-culture with U87 glioma cells. As shown in Figure 10, JNK and p38 activation was stronger in CD4$^+$ T cells expressing IL13-CD28-41BBζ than in those expressing IL13ζ. See Figure 10. In contrast, activation of another MAPK, ERK, was comparable between the two cell types. Activation of AKT was observed in both T cell populations, but was elevated only up to 24 hours in IL13ζ$^+$ cells while IL13-CD28-41BBζ$^+$ cells displayed elevated AKT activity for up to 72 hours or more. See Figure 10B. Thus, both CARs were effective, but the costimulatory domains within the IL13-CD28-41BBζ CAR produced more sustained AKT activity compared to that observed with the IL13ζ CAR.

Example 3. Costimulation Signals Enforce Th_1 Polarization of Tumor Re-directed $CD4^+$ Effectors.

[00071] Because p38 activity has been detected in Th_1 but not Th_2 cells, and JNK/p38 activation is known to induce Th_1 production of associated TNF-α and IFN-γ cytokines, the effect of CD28 and 4-1BB costimulatory function on CAR-mediated induction of Th_1-associated cytokines was investigated. Genetically modified $CD4^+$ T cells (10^6 cells) expressing IL13ζ or IL13-CD28-41BBζ were co-cultured in 24-well tissue culture plates with different stimulator cells (5×10^5 cells) in 2 mL of culture medium. The stimulator cells were U87 glioma cells (U87), parental NS0 mouse myeloma cells (NS0), NS0 cells stably expressing surface IL13Rα2 (NS0-IL13Rα2) or NS0 cells stably expressing membrane bound OKT3 (NS0-OKT3) as indicated in Figure 11A.

[00072] Real-time quantitative RT-PCR (qPCR) was used to measure relative mRNA levels after culture. For gene expression analysis, total cellular RNA of the $CD4^+$ T cell transfectants was isolated using an RNeasy™ kit (Qiagen™). Reverse transcription of 5 µg total RNA in a volume of 30 mL (containing 1x reverse transcriptase buffer, 2.5 mM oligo dT, 0.25 mM dNTP, 0.01 M dithiothreitol, 20 U of Rnasin and 200 U of SuperScript™ II RNase H^- reverse transcriptase (Invitrogen™)) was used to synthesize cDNA. Samples were incubated at 42°C for 1 hour and the reverse transcriptase then was inactivated by heating 5 minutes at 70°C. Resulting cDNA, equivalent to 0.2 µg of total RNA, was subjected to qPCR analysis using SYBR Green™ PCR master mix (Applied Biosystems™) and designed primers by DNA Engine Opticon 2™ real time PCR detection system (MJ Research Inc.™). Primer sequences of the tested genes IL2 and IFN-γ are as follows: IL2 forward: CAAGAATCCCAAACTCACCAG, SEQ ID NO: 50; IL2 reverse: CGTTGATATTGCTGATTAAGTCC, SEQ ID NO: 51; IFN-γ forward: ATCCCAGTAATGGTTGTCCTGCCT, SEQ ID NO: 52; IFN-γ reverse: TCTTGCTTAGGTTGGCTGCCTAGT, SEQ ID NO: 53. The average cycle threshold value (CT) of cyclophilin mRNA (as described in Chang et al., "The E3 ubiquitin ligase itch couples JAK activation to TNFalpha-induced cell death by inducing c-FLIP(L) turnover." Cell 124:601-613, 2006) was used to normalize the tested genes. The

average CT values were determined by triplicate qPCR measurements for each gene in each experimental condition.

[00073] T cell total mRNA was collected at 0 hours (Figure 11A, white bars), 7 hours (Figure 11A, black bars) and 24 hours (Figure 11A, shaded bars) for qPCR analysis of the indicated human mRNAs. * indicates a $p < 0.05$ when compared to 7 hour values of IL13ζ-expressing $CD4^+$ T cells using an unpaired Student's t-test. The mouse myeloma line NS0 was electroporated with either IL13Rα2-IMPDH2_pMG (pJ00659), which confers expression of the IL13Rα2 target antigen and resistance to mycophenolic acid (MPA) or OKT3-IMPDH2_pcDNA3.1(+) (pJ01056), which confers expression of the CD3-crosslinking (and thus T cell stimulatory) OKT3 molecule along with resistance to MPA, and then cloned in the presence of 6 μM mycophenolic acid (MPA) and screened for human IL13Rα2 transgene expression. For the experiments using U87 and NS0-IL13Rα2 tumor cells, n = 3; for the experiment using NS0-OKT3 and NS0 tumor cells, n = 1.

[00074] The levels of IL2 and INF-γ mRNA were higher in IL13-CD28-41BBζ$^+$ T cells than in IL13ζ+ T cells after culture with U87 glioblastoma cells. See Figure 11A. No IL2 or INF-γ mRNA induction was observed with either T cell population when co-cultured with NS0 cells. Stimulation by IL13Rα2 transgene-expressing NS0 cells restored IL2 and INF-γ mRNA induction in IL13-CD28-41BBζ- but not in IL13ζ-expressing T cells, indicating that cytokine induction genes were IL13Rα2-dependent. The relative amounts of induced IL2 and INF-γ mRNA directly correlate with IL13Rα2 surface expression levels on U87 and transgene expressing-NS0 cells; the U87 level is higher than that of NS0-IL13Rα2 cells. In contrast, induction of the IL2 and INF-γ genes in IL13ζ$^+$ T cells was similar to that seen in IL13-CD28-41BBζ$^+$ T cells when each population was co-cultured with NS0 cells that stably expressed membrane bound OKT3, an agonist immunoglobulin molecule that activates T cells via engagement of CD3ε. These results indicate that the lower induction of IL2 and INF-γ mRNA mediated by the engagement of IL13ζ with IL13Rα2 is not due to an intrinsic defect in these T cells, but to the lack of CD28 and 4-1BB costimulatory domains within the CAR.

[00075] To quantitate the amounts of Th_1 versus Th_2 cytokine proteins released from these CAR-expressing T cells, supernatants from these co-cultures were assayed for cytokine content. After a 24-hour incubation, culture supernatants of IL13ζ^+ (white bars) or IL13-CD28-41BBζ^+ (black bars) were harvested and assayed for Th_1 and Th_2 cytokines by multiplex cytometric bead array using the human 17-Plex Panel™ kit per the manufacturer's instructions (Bio-Rad™ Laboratories). See Figure 11B.

[00076] U87 glioma or IL13Rα2$^+$ NS0 cells stimulated more Th_1 cytokine release (IL2, IFN-γ, TNF-α and GM-CSF) and less Th_2 cytokine release (IL5, IL10 and IL13) from IL13-CD28-41BBζ^+ T cells than from IL13ζ^+ T cells. Equivalent levels of Th_1 and Th_2 cytokines were produced by IL13ζ- and IL13-CD28-41BBζ-expressing CD4$^+$ T cells cultured with OKT3 expressing NS0 cells, indicating that these cells remain unpolarized upon polyclonal activation via endogenous CD3. Levels of cytokines were all low to undetectable when the T cells were cultured with parental NS0 cells. Levels of the Th_2 cytokine IL4 also were low to undetectable when the T cells were cultured with any of the tumor cell lines. Overall, these data show that the presence of CD28 and 4-1BB costimulatory domains within the CAR help drive CD4$^+$ T cell transcription and secretion of Th_1-like cytokines.

Example 4. Increase in Recycling Anti-tumor Lytic Activity in IL13-CD28-41BBζ^+ CD4$^+$ T cells.

[00077] To determine if costimulatory CAR affected the tumor specific cytotoxic activity of CD4$^+$ T cells, luminescent cytolytic assays (LCA) were performed to detect the firefly luciferase (ffLuc) transgene luminescence activity of tumor cells *in vitro*. This assay was performed as described by Brown et al., "Biophotonic cytotoxicity assay for high-throughput screening of cytolytic killing." J. Immunol. Meth. 297:39-52, 2005, with 0.14 mg/mL D-luciferin and using a Victor2™ Luminometer. Briefly, *ffLuc* transgene luminescence activity of tumor cells *in vitro* was analyzed by LCA with 0.14 mg/mL D-luciferin (Xeonogen™) using a Victor2™ luminometer. See Figure 12A, which shows

enhanced cytotoxic activity of IL13-CD28-41BBζ$^+$ CD4$^+$ T cells (■) against U87 targets compared to IL13ζ$^+$ CD4$^+$ T cells (○) at the indicated E:T ratio after 4 hours. The mean ± SE of triplicate values are indicated; * indicates a $p < 0.05$ using an unpaired Student's t-test.

[00078] After 4 hours of co-culture with *ffLuc*-transfected U87 target cells, IL13-CD28-41BBζ$^+$ cells displayed a statistically significant enhancement in lytic activity compared to IL13ζ$^+$ cells. If co-culture was extended to 48 hours, no difference in cytotoxic activity was observed between the IL13ζ- and IL13-CD28-41BBζ-expressing cells (100% specific lysis was reached with both cells). The data in Figure 12B indicate specific lysis by LCA assay after 48 hours of co-culture at an E:T ratio of 2:1, and then again after addition of fresh targets for another 48 hours of co-culture at an E:T ratio of 2:1. The mean ± SE of triplicate values are indicated; * indicates a $p < 0.05$ (paired Student's t-test) comparing IL13-CD28-41BBζ$^+$ CD4$^+$ T cells (black bars) to IL13ζ$^+$ CD4$^+$ T cells (white bars) in the indicated co-culture.

[00079] Perforin and granzyme B mRNA levels were equally upregulated in IL13ζ$^+$ and IL13-CD28-41BBζ$^+$ cells, suggesting that these CAR-expressing T cells can use similar mechanisms of killing. However, if fresh ffLuc$^+$ targets were added for a second round of 48 hour co-culture with the same CAR-expressing CD4$^+$ T cells, the IL13-CD28-41BBζ$^+$ cells displayed significantly higher lytic activity than IL13ζ$^+$ cells (Figure 12B). This suggests that the costimulatory CAR beneficially affects the duration and/or recycling of CD4$^+$ T cell killing activity.

[00080] To further examine this phenomenon, viability of U87 tumor cells was analyzed during co-culture with IL13ζ$^+$ or IL13-CD28-41BBζ$^+$ T cells using video time-lapse microscopy (VTLM) of co-cultures of $6x10^5$ adherent U87 glioma cells with $1.2x10^6$ IL13ζ- or IL13-CD28-41BBζ-expressing CD4$^+$ T cells. The cultures were washed 45 hours later and then re-cultured with fresh U87 glioma cells ($6x10^5$). Numbers of viable tumor cells were plotted over 42 hours (the first killing) and from 45 hours to 139 hours (the second killing). See Figure 12C.

[00081] Imaging was simultaneously undertaken in a 37°C warm room on four Eclipse TS100™ microscopes (Nikon™ Inc.), each equipped with a tungsten-halogen

lamp, GIF (green) filter, ELWD 0.3 NA condenser, Plan Fluor™ 4x/0.13 PhL DL infinity corrected objective lens, D10NLC 1x lensless C-mount adapter (Diagnostic Instruments™) and VCB-3524 B/W RS-170 video 1/2" CCD camera (Sanyo™ North America Corp.). To collect the data, $1.2x10^6$ T cells (in 200 µL Hank's balanced salt solution supplemented with 0.1% human serum albumin) were added to T-25 flasks containing $6x10^5$ adherent U87 cells (plated 1 day prior at 3×10^5 cells/flask). The flasks were allowed to equilibrate on the microscope stage for 30 minutes prior to imaging. Time-lapse acquisition rate was at 2-minute intervals. Several frames of tumor cells alone were acquired in each video, followed by addition of T cells, The combined cells then were recorded continuously for 80 hours. After adding the T cells, each flask was gassed with 5% CO_2 for 10 seconds and sealed with parafilm to insure good pH control (bicarbonate in HBSS) and stable focus, respectively. Images were acquired using the COH VTLF Camera Organizer and digitized at 640x480 pixels using a Matrox™ 4-channel frame grabber board. Viable tumor cell counts were performed at $\leq$10 hour intervals using the "Manually Count Objects" command in MetaMorph™ 6.33 (Universal Imaging/Molecular Devices™ Corp.). All datasets were imported into MetaMorph™ and saved as MetaMorph™ stacks and AVI movies.

[00082] The capacity of either of the genetically modified $CD4^+$ T cells to kill tumor cells during the first 42 hours of co-culture was substantially the same (almost 100% of the U87 cells were killed by 30 hours). However, in the second encounter with U87 tumor cells, the recovered IL13-CD28-41BBζ^+ T cells retained greater cytolytic activity than the IL13ζ^+ T cells. Importantly, enumeration of T cells prior to addition of U87 cells for a second time revealed that there were no significant differences in cell number. Furthermore, CFSE-based assays performed over 72 hours of co-culture with U87 cells revealed no differences in proliferation of IL13ζ^+ or IL13-CD28-41BBζ^+ T cells *in vitro*. This demonstrates that the greater cytolytic activity upon addition of fresh targets was not due to the presence of more killers, but to an enhanced ability of individual killers to function. Together, these data show that the costimulatory CAR supports the recycling and retention of $CD4^+$ T cell function.

Example 5. Enhanced In Vivo Tumor Clearance by IL13-CD28-41BBζ$^+$ CD4$^+$ T Cells.

[00083] The ability of CARs with CD28 and 4-1BB signaling domains to enhance the anti-tumor efficacy of CD4$^+$ T cells was assessed using established U87 tumors in an orthotopic murine xenograft model. For *in vivo* studies, the U87 cells were transfected with ffluc-zeocin_pcDNA3.1(+) (pJ00778, a plasmid expressing a protein fusion of the firefly luciferase enzyme and the zeocin drug resistance gene) and IL2(2)_HyTk-pMG (pJ00976, a plasmid expressing the IL2 cytokine and the selection/suicide fusion gene HyTK) using oligofectimine (Invitrogen™) according to the manufacturer's instructions and then cloned in the presence of 0.2 mg/mL Zeocin and 0.1 mg/mL Hygromycin.

[00084] To produce the orthotopic glioma xenograft model, mice were treated as follows. One day after irradiation with 250 rads, male 6- to 8-week-old NOD-*scid* mice were anesthetized, shaved and immobilized in a Cunningham™ Mouse/Neonatal Rat Adaptor stereotactic apparatus restraint (Stoelting™). Mice then received a stereotactically guided injection of tumor (U87 glioma) 2 mm lateral and 0.5 mm anterior to Bregma over 3-5 mm. U87-ffLucZeo/IL2$^+$ tumor cells (2 x 10^5 cells/mouse), suspended in 2 µL of phenol-free RPMI (Irvine Scientific, Irvine, CA), were injected at a depth of 2.5 mm from the dura. Seven days after tumor inoculation, 10^6 T cells expressing either IL13ζ or IL13-CD28-41BBζ were delivered (adoptively transferred) in 2 µL to the tumor coordinates in the cerebrum. Control animals received PBS only ("sham control"). Burr holes were sealed with bone-wax and the incision closed with Nexaband™ glue. Animals received a subcutaneous injection of 0.1 mg/kg Buprenex™ for post-surgical recovery. In this model, tumors start to spontaneously regress at 13-14 days after injection due to recovery of the endogenous immune system, so experiments were completed by day 12.

[00085] Orthotopic tumor growth can be quantitated noninvasively by monitoring ffLuc flux signals derived from tumors in established U87 glioblastoma cells that stably express firefly luciferase (ffLuc) and human IL2. The *in vivo* luciferase activity was detected using in vivo biophotonic tumor imaging in mice with the Xenogen™ In Vivo Imaging System (IVIS) as previously described by Kahlon et al., "Specific recognition

and killing of glioblastoma multiforme by interleukin 13-zetakine redirected cytolytic T cells." Cancer Res. 64:9160-9166, 2004. Briefly, to monitor ffLuc flux, mice were injected intraperitoneally with 4.29 mg D-luciferin, anesthetized (1.5 L/min Oxygen + 4% Isoflurane), and light emission was measured over an integration time of 1 minute at 14 minutes post injection of luciferin. The flux (photons/second) was quantitated as total counts measured over time in the region of interest. See results in Figure 13. The values on the Y-axis represent the mean I SD of total flux levels of $ffLuc^+$ tumors from sham and treated groups (n = 6 for each group) at the indicated days after tumor engraftment. "Tx" indicates treatment with adoptively transferred T cells.

[00086] Prior to adoptive transfer of CAR-expressing $CD4^+$ T cells, all the mice exhibited increasing levels of tumor-derived ffLuc flux signals as expected (see Figure 13; compare days 2 and 6 after tumor engraftment). Two days following adoptive transfer (Tx), tumor ffLuc flux levels were reduced in the mice treated with either IL13ζ- or IL13-CD28-41BBζ-expressing T cells, when compared to the sham treated mice. However, 5 days post T cell treatment (day 12 after engraftment), tumor flux signals in the mice treated with IL13-CD28-41BBζ^+ T cells remained low, while flux signals from mice treated with IL13ζ^+ T cells had increased to a level similar to that of the sham treated (control) group. The costimulatory signaling domains of CD28 and 4-1BB thus enhanced and/or prolonged tumor growth control by the genetically re-directed T cells.

Example 6. Preparation of T cells suitable for therapy.

[00087] T lymphocytes were obtained from a patient by leukopheresis, and the autologous T cells were genetically altered to express the CAR, then administered back to the patient to achieve anti-cancer therapy.

[00088] To prepare IL13ζ^+ T cells suitable for therapeutic use, mononuclear cells were separated from leukopheresed blood by centrifugation over clinical grade Ficoll™. PBMC were washed twice in sterile phosphate-buffered saline containing 0.526 mM EDTA and then once in sterile PBS, and suspended in culture media consisting of RPMI

1640 HEPES, 10% heat inactivated FCS, and 4 mM L-glutamine. T cells present in patient PBMC were polyclonally activated by addition of Orthoclone™ OKT3 (30 ng/mL) to the culture. Cell cultures then were incubated in vented T-75 tissue culture flasks in the study subject's designated incubator. Twenty-four hours after initiation of culture, rhIL2 was added at 25 U/mL. Three days after the initiation of culture, PBMC were harvested, centrifuged, and resuspended in hypotonic electroporation buffer at $20x10^6$ cells/mL. Twenty-five micrograms of the plasmid IL13ζ/HyTK-pMG, together with 400 µL of cell suspension, were added to a sterile 0.2 cm electroporation cuvette. Each cuvette was subjected to a single electrical pulse of 250V/40µs and again incubated for ten minutes at room temperature. Surviving cells were harvested from cuvettes, pooled, and resuspended in culture media containing 25 U/mL rhIL2. Flasks were placed in the patient's designated tissue culture incubator. Three days following electroporation, hygromycin was added to cells at a final concentration of 0.2 mg/mL. Electroporated PBMC were cultured for a total of 14 days with media and IL2 supplementation every 48 hours.

[00089] The cloning of hygromycin-resistant $CD8^+$ CTL from electroporated OKT3-activated patient PBMC was initiated on day 14 of culture. Briefly, viable patient PBMC were added to a mixture of $100x10^6$ cryopreserved irradiated feeder PBMC and $20x10^6$ irradiated TM-LCL (EBV-transformed lymphoblastoid cells that act as feeder cells) in a volume of 200 mL of culture media containing 30 ng/mL OKT3 and 50 U/mL rhIL2. This mix was plated 0.2 mL into each well of ten 96-well cloning plates. Plates were wrapped in aluminum foil to decrease evaporative loss and placed in the patient's designated tissue culture incubator. On day 19 of culture, each well received hygromycin to a final concentration of 0.2 mg/mL. Wells were visually inspected for cellular outgrowth on an inverted microscope at Day 30 and positive wells were marked for restimulation.

[00090] The contents of each cloning well with cell growth were individually transferred to T-25 flasks containing $50x10^6$ irradiated PBMC, $10x10^6$ irradiated LCL, and 30ng/mL OKT3 in 25 mL tissue culture media. On days 1, 3, 5, 7, 9, 11, and/or 13 after restimulation, flasks received 50 U/mL rhIL2 and 15 mL fresh media when needed. On day 5 of the stimulation cycle, flasks also were supplemented with hygromycin 0.2

mg/mL. Fourteen days after seeding, cells were harvested, counted, and restimulated in T-75 flasks containing 100 x 10^6 irradiated PBMC, 20 x 10^6 irradiated TM-LCL and 30 ng/mL OKT3 in 50 mL tissue culture media. Flasks received additions to culture of rhIL2 and hygromycin as outlined above.

[00091] CTL selected for expansion for possible use in therapy were analyzed by immunofluorescence on a fluorescence-activated cell sorter, using FITC-conjugated monoclonal antibodies WT/31 (aβTCR), Leu 2a (CD8), and OKT4 (CD4) to confirm the clone phenotype ($\alpha\beta TCR^+$, $CD4^-$, $CD8^+$, and $IL13^+$). Criteria for selection of clones for clinical use included uniform TCR $\alpha\beta^+$, $CD4^-$, $CD8^+$ and $IL13^+$ as compared to isotype control FITC/PE-conjugated antibody. A single site of plasmid vector chromosomal integration was confirmed by Southern blot analysis. DNA from genetically modified T cell clones were screened with a DNA probe specific for the plasmid vector.

[00092] Expression of IL13-CD28-41BBζ was determined by western blot to detect chimeric receptor protein using the anti-CD3ζ zeta chain antibody described above according to standard methods. Briefly, whole cell lysates of transfected T cell clones were generated by lysis of 2 x 10^7 washed cells in 1 mL RIPA buffer (PBS, 1% NP40, 0.5% sodium deoxycholate, 0.1% SDS) containing 1 tablet/10 mL Complete Protease Inhibitor Cocktail. After an 80-minute incubation on ice, aliquots of centrifuged whole cell lysate supernatant were harvested and boiled in an equal volume of loading buffer under reducing conditions then subjected to SDS-PAGE electrophoresis on a precast 12% acrylamide gel. Following transfer to nitrocellulose, the membrane then was blocked in Blotto™ solution containing 4% non-fat dried milk in T-TBS (0.1% Tween 20™ in Tris buffered saline, pH 8.0) for one hour. Membranes were washed in T-TBS, then incubated with primary mouse anti-human CD3ζ monoclonal antibody 8D3 (Pharmingen™) at a concentration of 0.5 µg/mL for one hour. Following an additional four washes in T-TBS, membranes were incubated with a 1:3000 dilution (in Blotto™ solution) of goat anti-mouse IgG alkaline phosphatase-conjugated secondary antibody for 1 hour. Prior to adding substrate, membranes were rinsed in T-TBS, then incubated with 3 mL phosphatase substrate solution (Bio-Rad™ ImmunoStar™ kit) according to the manufacturer's instructions.

[00093] Suitable doses for a therapeutic effect are between about 10^6 and about 10^9 cells per dose, preferably in a series of dosing cycles. A preferred dosing regimen consists of four one-week dosing cycles of escalating doses, starting at about 10^7 cells on Day 0, increasing incrementally up to a target dose of about 10^8 cells by Day 5. Suitable modes of administration include intravenous, subcutaneous, intracavitary (for example by reservoir-access device), intraperitoneal, and direct injection into a tumor mass.

Example 7. Treatment of Intracranial Recurrent Glioma in Human Patients.

[00094] Treatment of glioma or any other cancer as described herein using IL13-CD28-41BBζ-expressing T cells according to this invention was performed as follows. T cell clones, preferably as described in Example 6, were selected for:

a. TCRα/β$^+$, CD4$^-$, CD8$^+$, IL13$^+$ cell surface phenotype;

b. the presence of a single copy of chromosomally integrated plasmid vector DNA;

c. expression of the IL13-CD28-41BBζ protein;

d. specific lysis of human IL13Rα2$^+$ targets;

e. dependence on exogenous IL2 for *in vitro* growth;

f. mycoplasma, fungal and bacterial sterility and endotoxin levels less than 5 EU/mL; and

g. *in vitro* sensitivity of clones to ganciclovir.

[00095] Peripheral blood mononuclear cells were obtained from the patient by leukopheresis, preferably following recovery from initial resection surgery and at a time at least three weeks from tapering off steroids and/or their most recent systemic chemotherapy. The target leukopheresis mononuclear cell yield generally was $5x10^9$ and the target number of hygromycin-resistant cytolytic T cell clones was 25. In general, at least five clones were identified that met all quality control parameters for *in vitro* expansion. Clones were cryopreserved and patients monitored by serial radiographic

and clinical examinations. When recurrence of progression of disease was documented, patients underwent a re-resection and/or placement of a reservoir-access device for delivering T cells to the tumor resection cavity.

[00096] Following recovery from surgery and tapering of steroids, if applicable, the patient commenced T cell therapy as follows. The patient received a target of at least four one-week cycles of therapy. During the first cycle, cell dose escalation proceeded from an initial dose on Day 0 of about 10^7 cells, followed by about $5x10^7$ cells on Day 3 to a target dose of about 10^8 cells on Day 5. Cycle 2 commenced as early as one week from commencement of cycle 1. On the days of T cell administration, expanded clones were aseptically processed by washing twice in 50cc of PBS then resuspended in pharmaceutical preservative-free normal saline in a volume that resulted in the cell dose for patient delivery in 2 mL. Preferably, T cells were instilled over 5-10 minutes, followed by a 2 mL PFNS flush administered over 5 minutes. Response to therapy was assessed by MRI +/- gandolinium, with spectroscopy.

[00097] In general, cell doses were at least a log less than doses given in studies employing intracavitary LAK cells (individual cell doses up to 10^9 and cumulative cell numbers as high as $2.75x10^{10}$), ex vivo expanded TILs (up to 10^9 cells/dose) and allo-reactive lymphocyte (starting cell dose 10^8 with cumulative cell doses up to $51.5x10^8$). Low-dose repetitive dosing is favored to avoid potentially dangerous inflammatory responses that might occur with single large cell number instillations. Each infusion preferably consisted of a single T cell clone, and the same clone preferably was administered throughout a patient's treatment course.

[00098] Those patients demonstrating tumor regression with residual disease on MRI may have additional courses of therapy beginning no earlier than Week 7, consisting of repetition of Cycles 3 and 4 followed by one week of rest/restaging provided these treatments are well tolerated until such time that disease progression is documented, or a complete response (CR) is achieved based on radiographic evaluation. Maximum toxicities generally accepted are less than grade 3, however this is at the discretion of the treating physician.

[00099] Treatment with ganciclovir leads to the ablation of CAR^+ $HyTK^+$ $CD8^+$ CTL clones. Therefore, any side effects associated with therapy (headache, fever, chills, nausea, etc.) which may occur can be managed using established treatments appropriate for the condition. For example, the patient may receive ganciclovir if any new grade 3 toxicity that progresses to grade 4, or any grade 4 treatment-related toxicity is observed that, in the opinion of the treating physician, puts the patient in significant medical danger. Parentally administered ganciclovir is dosed at 10 mg/kg/day divided every 12 hours. Patients should be hospitalized for the first 72 hours of ganciclovir therapy for monitoring purposes. If symptoms do not respond to ganciclovir within 48 hours, additional immunosuppressive agents, including but not limited to corticosteroids and cyclosporin, may be added at the discretion of the treating physician. If toxicities are severe, decadron and/or other immunosuppressive drugs along with ganciclovir also may be used at the discretion of the treating physician.

[000100] Preliminary safety studies using the protocol outlined above, where IL13-CAR-expressing CTL clones were administered to human patients with intracranial recurrent glioma, indicated that of the adverse events that had possible correlation with the intracavitary administration of T cells, the only Grade 3 events have been headaches that occurred with administration of 10^8 cells in each of the two patients treated to date. At no time were Grade 4 or 5 adverse events found to be associated with administration of the genetically altered T cells. Thus, the overall safety profile of this adoptive transfer therapy here was acceptable.

Examples 8-12. Exemplary CAR Molecules.

[000101] Figures 14-18 provide the sequences of additional CARs according to the invention. These serve as non-limiting examples of embodiments of the invention.

[000102] Figure 14 provides the sequence of an IL13-IgG_4-cd28tm-CD28gg-Zeta (CO) CAR (SEQ ID NO:36). This sequence encodes (1) the IL13 molecule with the E13Y mutation (which is the ligand for the tumor surface receptor IL13Rα2 on the tumor

surface (IL13)), (2) the Fc portion of the immunoglobulin isotype G_4 extracellular domain (IgG_4), (3) the transmembrane portion of the costimulatory molecule CD28 (cd28tm), (4) the signaling domain of CD28 with two leucines changed to glycines for the purpose of increased expression (CD28gg), and (5) the signaling domain of the CD3ζ chain of the T cell receptor (Zeta). All of the segments were codon optimized (CO) for increased mammalian expression. The underlined portion of the sequence is the coding sequence for CD28gg.

[000103] Figure 15 provides the sequence of an IL13-IgG_4-cd4tm-CD28-4-1BB-Zeta CAR (also referred to herein as IL13-CD28-41BBζ; SEQ ID NO:37). This sequence encodes (1) the IL13 molecule with the E13Y mutation (which is the ligand for the tumor surface receptor IL13Rα2 on the tumor surface (IL13)), (2) the Fc portion of the immunoglobulin isotype G_4 extracellular domain (IgG_4), (3) the transmembrane portion of CD4 (cd4tm); the signaling domain of the costimulatory molecule CD28 (CD28)(4) the signaling domain of the costimulatory molecule 4-1BB (4-1BB), and (5) the signaling domain of the CD3ζ chain of the T cell receptor (Zeta). The underlined portion of the sequence encodes CD28 and the Bold portion of the sequence encodes 4-1BB.

[000104] Figure 16 provides the sequence of an IL13-IgG_4-cd28tm-CD28-Ox40-Zeta CAR (SEQ ID NO:38). This sequence encodes (1) the IL13 molecule with the E13Y mutation (which is the ligand for the tumor surface receptor IL13Rα2 on the tumor surface (IL13)), (2) the Fc portion of the immunoglobulin isotype G_4 extracellular domain (IgG_4), (3) the transmembrane portion of the costimulatory molecule CD28 (cd28tm), (4) the signaling domain of CD28 (CD28), (5) the signaling domain of the costimulatory molecule OX-40 (Ox40), and (6) the signaling domain of the CD3z chain of the T cell receptor (Zeta). The sequence encoding cd28tm is underlined (amino acids 364-390); the sequence encoding CD28 is in italics (amino acids 391-431); the sequence encoding Ox40 is in bold (amino acids 432-467); and the sequence encoding Zeta is both underlined and in italics (amino acids 468-580).

[000105] Figure 17 provides the sequence of an IL13-IgG_4-cd28tm-CD28gg-4-1BB-Zeta CAR (SEQ ID NO:39). This sequence encodes (1) the IL13 molecule with the E13Y mutation (which is the ligand for the tumor surface receptor IL13Rα2 on the tumor

surface (IL13)), (2) the Fc portion of the immunoglobulin isotype G_4 extracellular domain (IgG_4), (3) the transmembrane portion of the costimulatory molecule CD28 (cd28tm), (4) the signaling domain of CD28 with two leucines changed to glycines for the purpose of increased expression (CD28gg), (5) the signaling domain of the costimulatory molecule 4-1BB (4-1BB), and (6) the signaling domain of the CD3ζ chain of the T cell receptor (Zeta). The underlined portion of the sequence encodes CD28gg and the bold portion of the sequence encodes 4-1BB.

[000106] Figure 18 provides the sequence of an IL13-IgG_4-cd28tm-CD28gg^199-4-1BB-Zeta CAR (SEQ ID NO:40). This sequence encodes (1) the IL13 molecule with the E13Y mutation (which is the ligand for the tumor surface receptor IL13Rα2 on the tumor surface (IL13)), (2) the Fc portion of the immunoglobulin isotype G_4 extracellular domain (IgG_4), (3) the transmembrane portion of the costimulatory molecule CD28 (cd28tm), (4) the signaling domain of CD28 with two leucines changed to glycines for the purpose of increased expression, and its kinase domain deleted for the purpose of removing its signaling activity (i.e., as a negative control for SEQ ID NO:39) (CD28gg^199), (5) the signaling domain of the costimulatory molecule 4-1BB (4-1BB), and (6) the signaling domain of the CD3ζ chain of the T cell receptor (Zeta). The underlined portion of the sequence encodes CD28gg^199 and the bold portion of the sequence encodes 4-1BB.

The embodiments of the present invention for which an exclusive property or privilege is claimed are defined as follows:

1. A chimeric antigen receptor (CAR) which is encoded by the DNA sequence of SEQ ID NO: 37.

2. An isolated T lymphocyte that expresses the CAR of claim 1.

3. A T lymphocyte that expresses the CAR of claim 1 for use in cancer immunotherapy.

4. The T lymphocyte of claim 2 for use in cancer immunotherapy.

5. The T lymphocyte of claim 3 or claim 4 wherein said cancer is selected from the group consisting of glioblastoma, medulloblastoma, breast cancer, head and neck cancer, kidney cancer, ovarian cancer, Kaposi's sarcoma, acute myelogenous leukemia, and B-lineage malignancies.

Date Reçue/Date Received 2020-07-15

FIG. 1

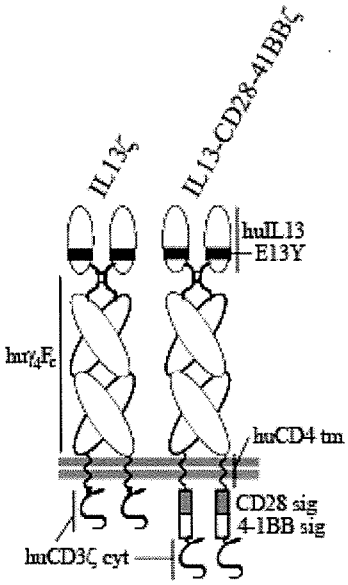

IL13ζ
IL13-CD28-4IBBζ
huIL13
E13Y
huγ4Fc
huCD4 tm
CD28 sig
4-1BB sig
huCD3ζ cyt

FIG. 2

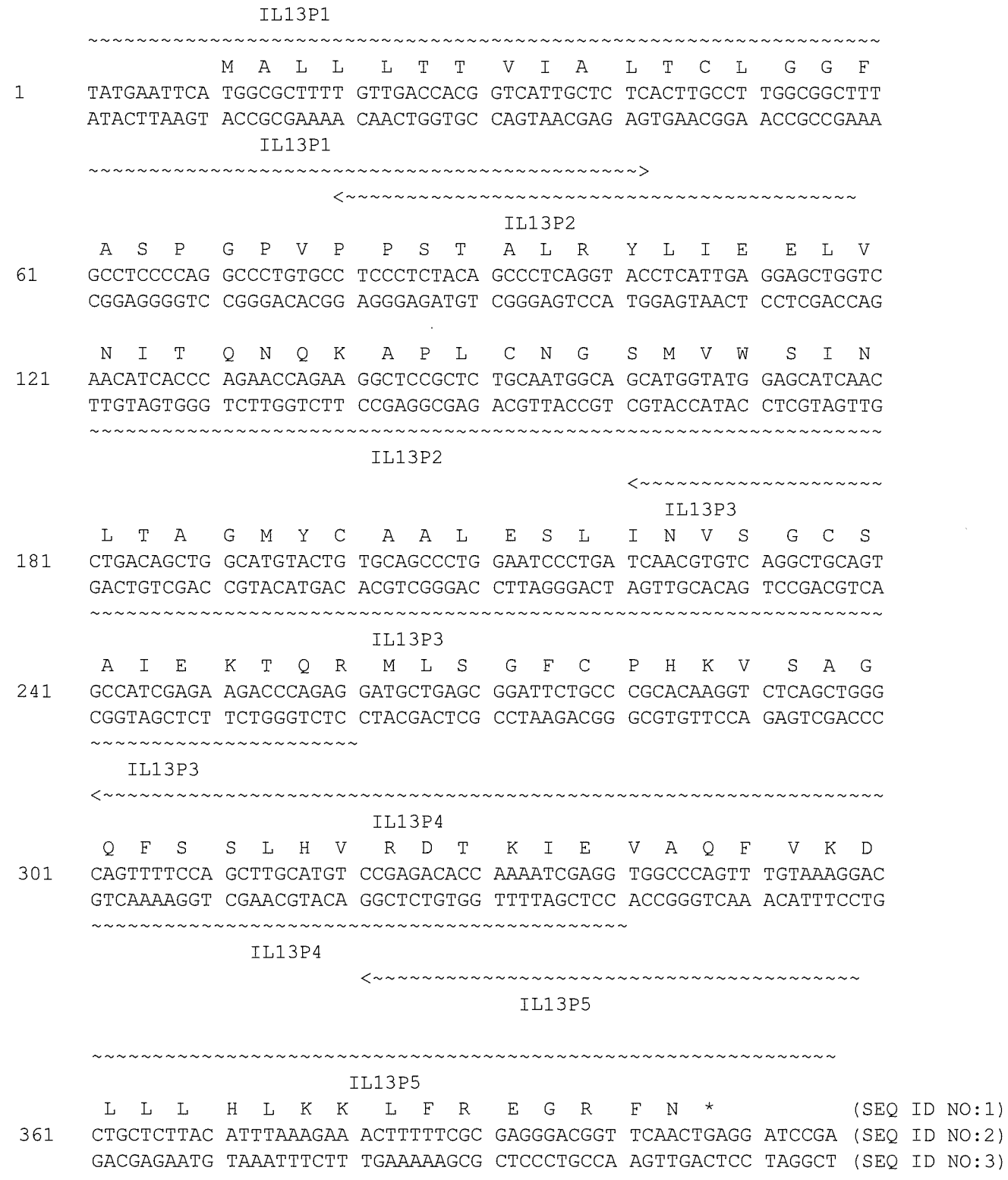

IL13P1
M A L L L T T V I A L T C L G G F
1 TATGAATTCA TGGCGCTTTT GTTGACCACG GTCATTGCTC TCACTTGCCT TGGCGGCTTT
ATACTTAAGT ACCGCGAAAA CAACTGGTGC CAGTAACGAG AGTGAACGGA ACCGCCGAAA
IL13P1
IL13P2
A S P G P V P P S T A L R Y L I E E L V
61 GCCTCCCCAG GCCCTGTGCC TCCCTCTACA GCCCTCAGGT ACCTCATTGA GGAGCTGGTC
CGGAGGGGTC CGGGACACGG AGGGAGATGT CGGGAGTCCA TGGAGTAACT CCTCGACCAG
N I T Q N Q K A P L C N G S M V W S I N
121 AACATCACCC AGAACCAGAA GGCTCCGCTC TGCAATGGCA GCATGGTATG GAGCATCAAC
TTGTAGTGGG TCTTGGTCTT CCGAGGCGAG ACGTTACCGT CGTACCATAC CTCGTAGTTG
IL13P2
IL13P3
L T A G M Y C A A L E S L I N V S G C S
181 CTGACAGCTG GCATGTACTG TGCAGCCCTG GAATCCCTGA TCAACGTGTC AGGCTGCAGT
GACTGTCGAC CGTACATGAC ACGTCGGGAC CTTAGGGACT AGTTGCACAG TCCGACGTCA
IL13P3
A I E K T Q R M L S G F C P H K V S A G
241 GCCATCGAGA AGACCCAGAG GATGCTGAGC GGATTCTGCC CGCACAAGGT CTCAGCTGGG
CGGTAGCTCT TCTGGGTCTC CTACGACTCG CCTAAGACGG GCGTGTTCCA GAGTCGACCC
IL13P3
IL13P4
Q F S S L H V R D T K I E V A Q F V K D
301 CAGTTTTCCA GCTTGCATGT CCGAGACACC AAAATCGAGG TGGCCCAGTT TGTAAAGGAC
GTCAAAAGGT CGAACGTACA GGCTCTGTGG TTTTAGCTCC ACCGGGTCAA ACATTTCCTG
IL13P4
IL13P5
IL13P5
L L L H L K K L F R E G R F N * (SEQ ID NO:1)
361 CTGCTCTTAC ATTTAAAGAA ACTTTTTCGC GAGGGACGGT TCAACTGAGG ATCCGA (SEQ ID NO:2)
GACGAGAATG TAAATTTCTT TGAAAAAGCG CTCCCTGCCA AGTTGACTCC TAGGCT (SEQ ID NO:3)

FIG. 3A

```
                          M   L   L   L   V   T   S   L   L   L   C   E   L   P
1     ATCTCTAGAG CCGCCACCAT GCTTCTCCTG GTGACAAGCC TTCTGCTCTG TGAGTTACCA
      TAGAGATCTC GGCGGTGGTA CGAAGAGGAC CACTGTTCGG AAGACGAGAC ACTCAATGGT

       H   P   A   F   L   L   I   P   G   P   V   P   P   S   T   A   L   R   Y   L
61    CACCCAGCAT TCCTCCTGAT CCCAGGCCCT GTGCCTCCCT CTACAGCCCT CAGGTACCTC
      GTGGGTCGTA AGGAGGACTA GGGTCCGGGA CACGGAGGGA GATGTCGGGA GTCCATGGAG

       I   E   E   L   V   N   I   T   Q   N   Q   K   A   P   L   C   N   G   S   M
121   ATTGAGGAGC TGGTCAACAT CACCCAGAAC CAGAAGGCTC CGCTCTGCAA TGGCAGCATG
      TAACTCCTCG ACCAGTTGTA GTGGGTCTTG GTCTTCCGAG GCGAGACGTT ACCGTCGTAC

       V   W   S   I   N   L   T   A   G   M   Y   C   A   A   L   E   S   L   I   N
181   GTATGGAGCA TCAACCTGAC AGCTGGCATG TACTGTGCAG CCCTGGAATC CCTGATCAAC
      CATACCTCGT AGTTGGACTG TCGACCGTAC ATGACACGTC GGGACCTTAG GGACTAGTTG

       V   S   G   C   S   A   I   E   K   T   Q   R   M   L   S   G   F   C   P   H
241   GTGTCAGGCT GCAGTGCCAT CGAGAAGACC CAGAGGATGC TGAGCGGATT CTGCCCGCAC
      CACAGTCCGA CGTCACGGTA GCTCTTCTGG GTCTCCTACG ACTCGCCTAA GACGGGCGTG

       K   V   S   A   G   Q   F   S   S   L   H   V   R   D   T   K   I   E   V   A
301   AAGGTCTCAG CTGGGCAGTT TTCCAGCTTG CATGTCCGAG ACACCAAAAT CGAGGTGGCC
      TTCCAGAGTC GACCCGTCAA AAGGTCGAAC GTACAGGCTC TGTGGTTTTA GCTCCACCGG

       Q   F   V   K   D   L   L   L   H   L   K   K   L   F   R   E   G   R   F   N
361   CAGTTTGTAA AGGACCTGCT CTTACATTTA AAGAAACTTT TTCGCGAGGG ACGGTTCAAC
      GTCAAACATT TCCTGGACGA GAATGTAAAT TTCTTTGAAA AAGCGCTCCC TGCCAAGTTG

       E   S   K   Y   G   P   P   C   P   P   C   P   A   P   E   F   L   G   G   P
421   GAGTCCAAAT ATGGTCCCCC ATGCCCACCA TGCCCAGCAC CTGAGTTCCT GGGGGGACCA
      CTCAGGTTTA TACCAGGGGG TACGGGTGGT ACGGGTCGTG GACTCAAGGA CCCCCCTGGT

       S   V   F   L   F   P   P   K   P   K   D   T   L   M   I   S   R   T   P   E
481   TCAGTCTTCC TGTTCCCCCC AAAACCCAAG GACACTCTCA TGATCTCCCG GACCCCTGAG
      AGTCAGAAGG ACAAGGGGGG TTTTGGGTTC CTGTGAGAGT ACTAGAGGGC CTGGGGACTC

       V   T   C   V   V   V   D   V   S   Q   E   D   P   E   V   Q   F   N   W   Y
541   GTCACGTGCG TGGTGGTGGA CGTGAGCCAG GAAGACCCCG AGGTCCAGTT CAACTGGTAC
      CAGTGCACGC ACCACCACCT GCACTCGGTC CTTCTGGGGC TCCAGGTCAA GTTGACCATG

       V   D   G   V   E   V   H   N   A   K   T   K   P   R   E   E   Q   F   N   S
601   GTGGATGGCG TGGAGGTGCA TAATGCCAAG ACAAAGCCGC GGGAGGAGCA GTTCAACAGC
      CACCTACCGC ACCTCCACGT ATTACGGTTC TGTTTCGGCG CCCTCCTCGT CAAGTTGTCG
```

FIG. 3B

```
      T  Y  R   V  V  S  V   L  T  V   L  H  Q   D  W  L  N   G  K  E
661   ACGTACCGTG TGGTCAGCGT CCTCACCGTC CTGCACCAGG ACTGGCTGAA CGGCAAGGAG
      TGCATGGCAC ACCAGTCGCA GGAGTGGCAG GACGTGGTCC TGACCGACTT GCCGTTCCTC

      Y  K  C   K  V  S  N   K  G  L   P  S  S   I  E  K  T   I  S  K
721   TACAAGTGCA AGGTCTCCAA CAAAGGCCTC CCGTCCTCCA TCGAGAAAAC CATCTCCAAA
      ATGTTCACGT TCCAGAGGTT GTTTCCGGAG GGCAGGAGGT AGCTCTTTTG GTAGAGGTTT

      A  K  G   Q  P  R  E   P  Q  V   Y  T  L   P  P  S  Q   E  E  M
781   GCCAAAGGGC AGCCCCGAGA GCCACAGGTG TACACCCTGC CCCCATCCCA GGAGGAGATG
      CGGTTTCCCG TCGGGGCTCT CGGTGTCCAC ATGTGGGACG GGGGTAGGGT CCTCCTCTAC

      T  K  N   Q  V  S  L   T  C  L   V  K  G   F  Y  P  S   D  I  A
841   ACCAAGAACC AGGTCAGCCT GACCTGCCTG GTCAAAGGCT TCTACCCCAG CGACATCGCC
      TGGTTCTTGG TCCAGTCGGA CTGGACGGAC CAGTTTCCGA AGATGGGGTC GCTGTAGCGG

      V  E  W   E  S  N  G   Q  P  E   N  N  Y   K  T  T  P   P  V  L
901   GTGGAGTGGG AGAGCAATGG GCAGCCGGAG AACAACTACA AGACCACGCC TCCCGTGCTG
      CACCTCACCC TCTCGTTACC CGTCGGCCTC TTGTTGATGT TCTGGTGCGG AGGGCACGAC

      D  S  D   G  S  F  F   L  Y  S   R  L  T   V  D  K  S   R  W  Q
961   GACTCCGACG GCTCCTTCTT CCTCTACAGC AGGCTAACCG TGGACAAGAG CAGGTGGCAG
      CTGAGGCTGC CGAGGAAGAA GGAGATGTCG TCCGATTGGC ACCTGTTCTC GTCCACCGTC

      E  G  N   V  F  S  C   S  V  M   H  E  A   L  H  N  H   Y  T  Q
1021  GAGGGGAATG TCTTCTCATG CTCCGTGATG CATGAGGCTC TGCACAACCA CTACACACAG
      CTCCCCTTAC AGAAGAGTAC GAGGCACTAC GTACTCCGAG ACGTGTTGGT GATGTGTGTC

      K  S  L   S  L  S  L   G  K  M   A  L  I   V  L  G  G   V  A  G
1081  AAGAGCCTCT CCCTGTCTCT GGGTAAAATG GCCCTGATTG TGCTGGGGGG CGTCGCCGGC
      TTCTCGGAGA GGGACAGAGA CCCATTTTAC CGGGACTAAC ACGACCCCCC GCAGCGGCCG

      L  L  L   F  I  G  L   G  I  F   F  R  V   K  F  S  R   S  A  D
1141  CTCCTGCTTT TCATTGGGCT AGGCATCTTC TTCAGAGTGA AGTTCAGCAG GAGCGCAGAC
      GAGGACGAAA AGTAACCCGA TCCGTAGAAG AAGTCTCACT TCAAGTCGTC CTCGCGTCTG

      A  P  A   Y  Q  Q  G   Q  N  Q   L  Y  N   E  L  N  L   G  R  R
1201  GCCCCCGCGT ACCAGCAGGG CCAGAACCAG CTCTATAACG AGCTCAATCT AGGACGAAGA
      CGGGGGCGCA TGGTCGTCCC GGTCTTGGTC GAGATATTGC TCGAGTTAGA TCCTGCTTCT

      E  E  Y   D  V  L  D   K  R  R   G  R  D   P  E  M  G   G  K  P
1261  GAGGAGTACG ATGTTTTGGA CAAGAGACGT GGCCGGGACC CTGAGATGGG GGGAAAGCCG
      CTCCTCATGC TACAAAACCT GTTCTCTGCA CCGGCCCTGG GACTCTACCC CCCTTTCGGC
```

FIG. 3C

```
      R  R  K   N  P  Q  E   G  L  Y   N  E  L   Q  K  D  K   M  A  E
1321  AGAAGGAAGA ACCCTCAGGA AGGCCTGTAC AATGAACTGC AGAAAGATAA GATGGCGGAG
      TCTTCCTTCT TGGGAGTCCT TCCGGACATG TTACTTGACG TCTTTCTATT CTACCGCCTC

      A  Y  S   E  I  G  M   K  G  E   R  R  R   G  K  G  H   D  G  L
1381  GCCTACAGTG AGATTGGGAT GAAAGGCGAG CGCCGGAGGG GCAAGGGGCA CGATGGCCTT
      CGGATGTCAC TCTAACCCTA CTTTCCGCTC GCGGCCTCCC CGTTCCCCGT GCTACCGGAA

      Y  Q  G   L  S  T  A   T  K  D   T  Y  D   A  L  H  M   Q  A  L
1441  TACCAGGGTC TCAGTACAGC CACCAAGGAC ACCTACGACG CCCTTCACAT GCAGGCCCTG
      ATGGTCCCAG AGTCATGTCG GTGGTTCCTG TGGATGCTGC GGGAAGTGTA CGTCCGGGAC

      P  P  R   *  (SEQ ID NO:4)
1501  CCCCCTCGCT AAGCGGCCGC AT  (SEQ ID NO:5)
      GGGGGAGCGA TTCGCCGGCG TA  (SEQ  ID NO:6)
```

GM-CSFR alpha signal peptide (nucleotides 18-84; SEQ ID NO:7)
IL13 (EmY) (nucleotides 85-420; SEQ ID NO:8)
IgG4 (SmP) (nucleotides 421-1107; SEQ ID NO:9)
CD4tm (nucleotides 1108-1173; SEQ ID NO:10)
CD3 zeta (nucleotides 1174-1512; SEQ ID NO:11)

FIG. 4

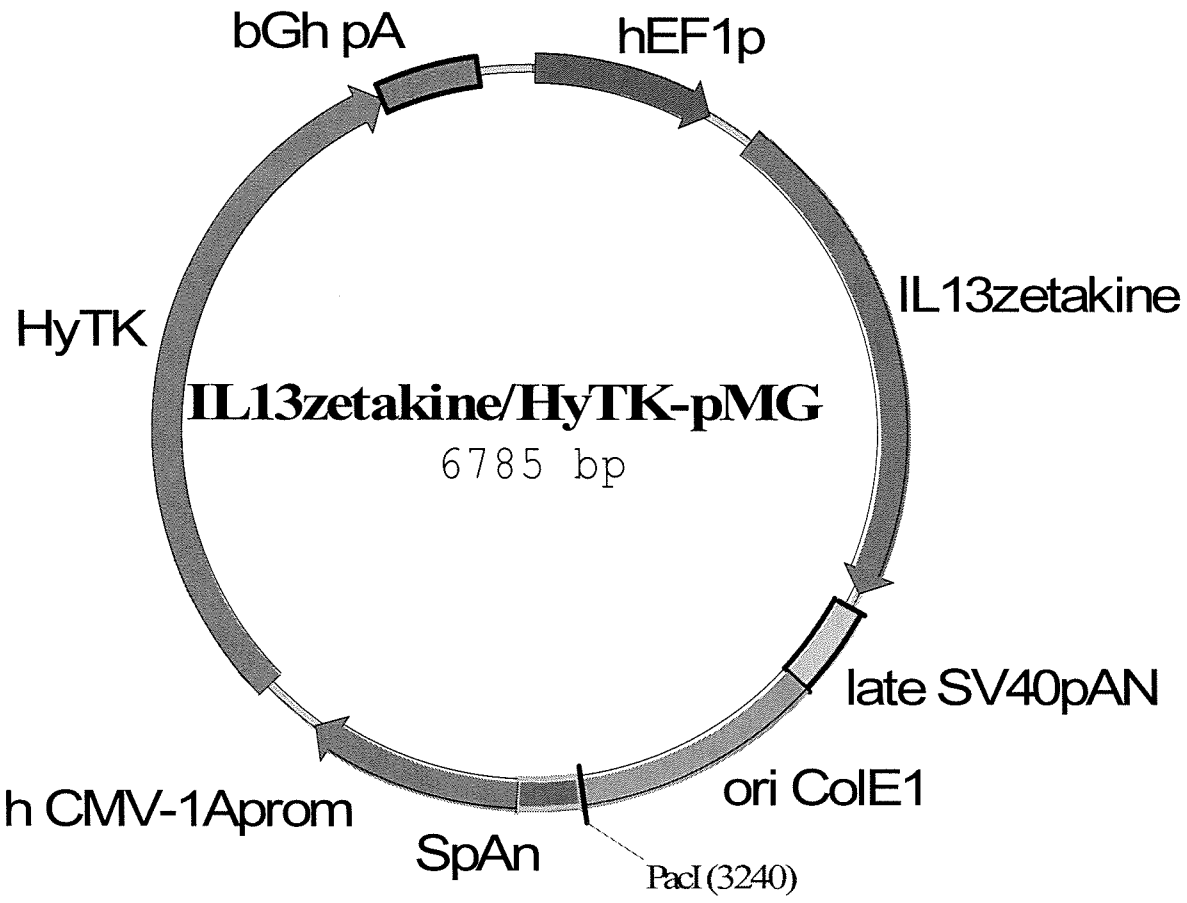

bGh pA
hEF1p
IL13zetakine
HyTK
IL13zetakine/HyTK-pMG
6785 bp
late SV40pAN
ori ColE1
h CMV-1Aprom
SpAn
PacI (3240)

FIG. 5A

(hEF1p→)

```
1     TCGAAGGATC TGCGATCGCT CCGGTGCCCG TCAGTGGGCA GAGCGCACAT CGCCCACAGT
      AGCTTCCTAG ACGCTAGCGA GGCCACGGGC AGTCACCCGT CTCGCGTGTA GCGGGTGTCA

61    CCCCGAGAAG TTGGGGGGAG GGGTCGGCAA TTGAACCGGT GCCTAGAGAA GGTGGCGCGG
      GGGGCTCTTC AACCCCCCTC CCCAGCCGTT AACTTGGCCA CGGATCTCTT CCACCGCGCC

121   GGTAAACTGG GAAAGTGATG TCGTGTACTG GCTCCGCCTT TTTCCCGAGG GTGGGGGAGA
      CCATTTGACC CTTTCACTAC AGCACATGAC CGAGGCGGAA AAAGGGCTCC CACCCCCTCT

181   ACCGTATATA AGTGCAGTAG TCGCCGTGAA CGTTCTTTTT CGCAACGGGT TTGCCGCCAG
      TGGCATATAT TCACGTCATC AGCGGCACTT GCAAGAAAAA GCGTTGCCCA AACGGCGGTC

241   AACACAGCTG AAGCTTCGAG GGGCTCGCAT CTCTCCTTCA CGCGCCCGCC GCCCTACCTG
      TTGTGTCGAC TTCGAAGCTC CCCGAGCGTA GAGAGGAAGT GCGCGGGCGG CGGGATGGAC

301   AGGCCGCCAT CCACGCCGGT TGAGTCGCGT TCTGCCGCCT CCCGCCTGTG GTGCCTCCTG
      TCCGGCGGTA GGTGCGGCCA ACTCAGCGCA AGACGGCGGA GGGCGGACAC CACGGAGGAC

361   AACTGCGTCC GCCGTCTAGG TAAGTTTAAA GCTCAGGTCG AGACCGGGCC TTTGTCCGGC
      TTGACGCAGG CGGCAGATCC ATTCAAATTT CGAGTCCAGC TCTGGCCCGG AAACAGGCCG

421   GCTCCCTTGG AGCCTACCTA GACTCAGCCG GCTCTCCACG CTTTGCCTGA CCCTGCTTGC
      CGAGGGAACC TCGGATGGAT CTGAGTCGGC CGAGAGGTGC GAAACGGACT GGGACGAACG

481   TCAACTCTAC GTCTTTGTTT CGTTTTCTGT TCTGCGCCGT TACAGATCCA AGCTGTGACC
      AGTTGAGATG CAGAAACAAA GCAAAAGACA AGACGCGGCA ATGTCTAGGT TCGACACTGG

541   GGCGCCTACG TAAGTGATAT CTACTAGATT TATCAAAAAG AGTGTTGACT TGTGAGCGCT
      CCGCGGATGC ATTCACTATA GATGATCTAA ATAGTTTTTC TCACAACTGA ACACTCGCGA

601   CACAATTGAT ACGGATTCAT CGAGAGGGAC ACGTCGACTA CTAACCTTCT TCTCTTTCCT
      GTGTTAACTA TGCCTAAGTA GCTCTCCCTG TGCAGCTGAT GATTGGAAGA AGAGAAAGGA
```

FIG. 5B

```
                                        (IL13zetakine→)
                                          M  L  L  L   V  T  S   L  L  L
661  ACAGCTGAGA TCACCCTAGA GCCGCCACCA TGCTTCTCCT GGTGACAAGC CTTCTGCTCT
     TGTCGACTCT AGTGGGATCT CGGCGGTGGT ACGAAGAGGA CCACTGTTCG GAAGACGAGA

     C  E  L  P   H  P  A   F  L  L  I   P  G  P   V  P  P   S  T  A
721  GTGAGTTACC ACACCCAGCA TTCCTCCTGA TCCCAGGCCC TGTGCCTCCC TCTACAGCCC
     CACTCAATGG TGTGGGTCGT AAGGAGGACT AGGGTCCGGG ACACGGAGGG AGATGTCGGG

     L  R  Y  L   I  E  E   L  V  N  I   T  Q  N   Q  K  A   P  L  C
781  TCAGGTACCT CATTGAGGAG CTGGTCAACA TCACCCAGAA CCAGAAGGCT CCGCTCTGCA
     AGTCCATGGA GTAACTCCTC GACCAGTTGT AGTGGGTCTT GGTCTTCCGA GGCGAGACGT

     N  G  S  M   V  W  S   I  N  L  T   A  G  M   Y  C  A   A  L  E
841  ATGGCAGCAT GGTATGGAGC ATCAACCTGA CAGCTGGCAT GTACTGTGCA GCCCTGGAAT
     TACCGTCGTA CCATACCTCG TAGTTGGACT GTCGACCGTA CATGACACGT CGGGACCTTA

     S  L  I  N   V  S  G   C  S  A  I   E  K  T   Q  R  M   L  S  G
901  CCCTGATCAA CGTGTCAGGC TGCAGTGCCA TCGAGAAGAC CCAGAGGATG CTGAGCGGAT
     GGGACTAGTT GCACAGTCCG ACGTCACGGT AGCTCTTCTG GGTCTCCTAC GACTCGCCTA

     F  C  P  H   K  V  S   A  G  Q  F   S  S  L   H  V  R   D  T  K
961  TCTGCCCGCA CAAGGTCTCA GCTGGGCAGT TTTCCAGCTT GCATGTCCGA GACACCAAAA
     AGACGGGCGT GTTCCAGAGT CGACCCGTCA AAAGGTCGAA CGTACAGGCT CTGTGGTTTT

     I  E  V  A   Q  F  V   K  D  L  L   L  H  L   K  K  L   F  R  E
1021 TCGAGGTGGC CCAGTTTGTA AAGGACCTGC TCTTACATTT AAAGAAACTT TTTCGCGAGG
     AGCTCCACCG GGTCAAACAT TTCCTGGACG AGAATGTAAA TTTCTTTGAA AAAGCGCTCC

     G  R  F  N   E  S  K   Y  G  P  P   C  P  P   C  P  A   P  E  F
1081 GACGGTTCAA CGAGTCCAAA TATGGTCCCC CATGCCCACC ATGCCCAGCA CCTGAGTTCC
     CTGCCAAGTT GCTCAGGTTT ATACCAGGGG GTACGGGTGG TACGGGTCGT GGACTCAAGG

     L  G  G  P   S  V  F   L  F  P  P   K  P  K   D  T  L   M  I  S
1141 TGGGGGGACC ATCAGTCTTC CTGTTCCCCC CAAAACCCAA GGACACTCTC ATGATCTCCC
     ACCCCCCTGG TAGTCAGAAG GACAAGGGGG GTTTTGGGTT CCTGTGAGAG TACTAGAGGG
```

FIG. 5C

```
     R  T  P  E   V  T  C   V  V  V  D   V  S  Q   E  D  P   E  V  Q
1201 GGACCCCTGA GGTCACGTGC GTGGTGGTGG ACGTGAGCCA GGAAGACCCC GAGGTCCAGT
     CCTGGGGACT CCAGTGCACG CACCACCACC TGCACTCGGT CCTTCTGGGG CTCCAGGTCA

     F  N  W  Y   V  D  G   V  E  V  H   N  A  K   T  K  P   R  E  E
1261 TCAACTGGTA CGTGGATGGC GTGGAGGTGC ATAATGCCAA GACAAAGCCG CGGGAGGAGC
     AGTTGACCAT GCACCTACCG CACCTCCACG TATTACGGTT CTGTTTCGGC GCCCTCCTCG

     Q  F  N  S   T  Y  R   V  V  S  V   L  T  V   L  H  Q   D  W  L
1321 AGTTCAACAG CACGTACCGT GTGGTCAGCG TCCTCACCGT CCTGCACCAG GACTGGCTGA
     TCAAGTTGTC GTGCATGGCA CACCAGTCGC AGGAGTGGCA GGACGTGGTC CTGACCGACT

     N  G  K  E   Y  K  C   K  V  S  N   K  G  L   P  S  S   I  E  K
1381 ACGGCAAGGA GTACAAGTGC AAGGTCTCCA ACAAAGGCCT CCCGTCCTCC ATCGAGAAAA
     TGCCGTTCCT CATGTTCACG TTCCAGAGGT TGTTTCCGGA GGGCAGGAGG TAGCTCTTTT

     T  I  S  K   A  K  G   Q  P  R  E   P  Q  V   Y  T  L   P  P  S
1441 CCATCTCCAA AGCCAAAGGG CAGCCCCGAG AGCCACAGGT GTACACCCTG CCCCCATCCC
     GGTAGAGGTT TCGGTTTCCC GTCGGGGCTC TCGGTGTCCA CATGTGGGAC GGGGGTAGGG

     Q  E  E  M   T  K  N   Q  V  S  L   T  C  L   V  K  G   F  Y  P
1501 AGGAGGAGAT GACCAAGAAC CAGGTCAGCC TGACCTGCCT GGTCAAAGGC TTCTACCCCA
     TCCTCCTCTA CTGGTTCTTG GTCCAGTCGG ACTGGACGGA CCAGTTTCCG AAGATGGGGT

     S  D  I  A   V  E  W   E  S  N  G   Q  P  E   N  N  Y   K  T  T
1561 GCGACATCGC CGTGGAGTGG GAGAGCAATG GGCAGCCGGA GAACAACTAC AAGACCACGC
     CGCTGTAGCG GCACCTCACC CTCTCGTTAC CCGTCGGCCT CTTGTTGATG TTCTGGTGCG

     P  P  V  L   D  S  D   G  S  F  F   L  Y  S   R  L  T   V  D  K
1621 CTCCCGTGCT GGACTCCGAC GGCTCCTTCT TCCTCTACAG CAGGCTAACC GTGGACAAGA
     GAGGGCACGA CCTGAGGCTG CCGAGGAAGA AGGAGATGTC GTCCGATTGG CACCTGTTCT

     S  R  W  Q   E  G  N   V  F  S  C   S  V  M   H  E  A   L  H  N
1681 GCAGGTGGCA GGAGGGGAAT GTCTTCTCAT GCTCCGTGAT GCATGAGGCT CTGCACAACC
     CGTCCACCGT CCTCCCCTTA CAGAAGAGTA CGAGGCACTA CGTACTCCGA GACGTGTTGG
```

FIG. 5D

```
     H  Y  T  Q   K  S  L   S  L  S  L   G  K  M   A  L  I   V  L  G
1741 ACTACACACA GAAGAGCCTC TCCCTGTCCC TAGGTAAAAT GGCCCTGATT GTGCTGGGGG
     TGATGTGTGT CTTCTCGGAG AGGGACAGGG ATCCATTTTA CCGGGACTAA CACGACCCCC

     G  V  A  G   L  L  L   F  I  G  L   G  I  F   F  R  V   K  F  S
1801 GCGTCGCCGG CCTCCTGCTT TTCATTGGGC TAGGCATCTT CTTCAGAGTG AAGTTCAGCA
     CGCAGCGGCC GGAGGACGAA AAGTAACCCG ATCCGTAGAA GAAGTCTCAC TTCAAGTCGT

     R  S  A  D   A  P  A   Y  Q  Q  G   Q  N  Q   L  Y  N   E  L  N
1861 GGAGCGCAGA CGCCCCCGCG TACCAGCAGG GCCAGAACCA GCTCTATAAC GAGCTCAATC
     CCTCGCGTCT GCGGGGGCGC ATGGTCGTCC CGGTCTTGGT CGAGATATTG CTCGAGTTAG

     L  G  R  R   E  E  Y   D  V  L  D   K  R  R   G  R  D   P  E  M
1921 TAGGACGAAG AGAGGAGTAC GATGTTTTGG ACAAGAGACG TGGCCGGGAC CCTGAGATGG
     ATCCTGCTTC TCTCCTCATG CTACAAAACC TGTTCTCTGC ACCGGCCCTG GGACTCTACC

     G  G  K  P   R  R  K   N  P  Q  E   G  L  Y   N  E  L   Q  K  D
1981 GGGGAAAGCC GAGAAGGAAG AACCCTCAGG AAGGCCTGTA CAATGAACTG CAGAAAGATA
     CCCCTTTCGG CTCTTCCTTC TTGGGAGTCC TTCCGGACAT GTTACTTGAC GTCTTTCTAT

     K  M  A  E   A  Y  S   E  I  G  M   K  G  E   R  R  R   G  K  G
2041 AGATGGCGGA GGCCTACAGT GAGATTGGGA TGAAAGGCGA GCGCCGGAGG GGCAAGGGGC
     TCTACCGCCT CCGGATGTCA CTCTAACCCT ACTTTCCGCT CGCGGCCTCC CCGTTCCCCG

     H  D  G  L   Y  Q  G   L  S  T  A   T  K  D   T  Y  D   A  L  H
2101 ACGATGGCCT TTACCAGGGT CTCAGTACAG CCACCAAGGA CACCTACGAC GCCCTTCACA
     TGCTACCGGA AATGGTCCCA GAGTCATGTC GGTGGTTCCT GTGGATGCTG CGGGAAGTGT

     M  Q  A  L   P  P  R   *
2161 TGCAGGCCCT GCCCCCTCGC TGAGCGGCCG GCGAAGGAGG CCTAGATCTA TCGATTGTAC
     ACGTCCGGGA CGGGGGAGCG ACTCGCCGGC CGCTTCCTCC GGATCTAGAT AGCTAACATG

              (Late SV40pAn→)
2221 AGCTAGCTCG ACATGATAAG ATACATTGAT GAGTTTGGAC AAACCACAAC TAGAATGCAG
     TCGATCGAGC TGTACTATTC TATGTAACTA CTCAAACCTG TTTGGTGTTG ATCTTACGTC
```

FIG. 5E

```
2281  TGAAAAAAAT GCTTTATTTG TGAAATTTGT GATGCTATTG CTTTATTTGT GAAATTTGTG
      ACTTTTTTTA CGAAATAAAC ACTTTAAACA CTACGATAAC GAAATAAACA CTTTAAACAC

2341  ATGCTATTGC TTTATTTGTA ACCATTATAA GCTGCAATAA ACAAGTTAAC AACAACAATT
      TACGATAACG AAATAAACAT TGGTAATATT CGACGTTATT TGTTCAATTG TTGTTGTTAA

2401  GCATTCATTT TATGTTTCAG GTTCAGGGGG AGGTGTGGGA GGTTTTTTAA AGCAAGTAAA
      CGTAAGTAAA ATACAAAGTC CAAGTCCCCC TCCACACCCT CCAAAAAATT TCGTTCATTT

                                                    (Ori ColE1→)
2461  ACCTCTACAA ATGTGGTAGA TCCATTTAAA TGTTAGCGAA GAACATGTGA GCAAAAGGCC
      TGGAGATGTT TACACCATCT AGGTAAATTT ACAATCGCTT CTTGTACACT CGTTTTCCGG

2521  AGCAAAAGGC CAGGAACCGT AAAAAGGCCG CGTTGCTGGC GTTTTTCCAT AGGCTCCGCC
      TCGTTTTCCG GTCCTTGGCA TTTTTCCGGC GCAACGACCG CAAAAAGGTA TCCGAGGCGG

2581  CCCCTGACGA GCATCACAAA AATCGACGCT CAAGTCAGAG GTGGCGAAAC CCGACAGGAC
      GGGGACTGCT CGTAGTGTTT TTAGCTGCGA GTTCAGTCTC CACCGCTTTG GGCTGTCCTG

2641  TATAAAGATA CCAGGCGTTT CCCCCTGGAA GCTCCCTCGT GCGCTCTCCT GTTCCGACCC
      ATATTTCTAT GGTCCGCAAA GGGGGACCTT CGAGGGAGCA CGCGAGAGGA CAAGGCTGGG

2701  TGCCGCTTAC CGGATACCTG TCCGCCTTTC TCCCTTCGGG AAGCGTGGCG CTTTCTCAAT
      ACGGCGAATG GCCTATGGAC AGGCGGAAAG AGGGAAGCCC TTCGCACCGC GAAAGAGTTA


2761  GCTCACGCTG TAGGTATCTC AGTTCGGTGT AGGTCGTTCG CTCCAAGCTG GGCTGTGTGC
      CGAGTGCGAC ATCCATAGAG TCAAGCCACA TCCAGCAAGC GAGGTTCGAC CCGACACACG

2821  ACGAACCCCC CGTTCAGCCC GACCGCTGCG CCTTATCCGG TAACTATCGT CTTGAGTCCA
      TGCTTGGGGG GCAAGTCGGG CTGGCGACGC GGAATAGGCC ATTGATAGCA GAACTCAGGT

2881  ACCCGGTAAG ACACGACTTA TCGCCACTGG CAGCAGCCAC TGGTAACAGG ATTAGCAGAG
      TGGGCCATTC TGTGCTGAAT AGCGGTGACC GTCGTCGGTG ACCATTGTCC TAATCGTCTC

2941  CGAGGTATGT AGGCGGTGCT ACAGAGTTCT TGAAGTGGTG GCCTAACTAC GGCTACACTA
      GCTCCATACA TCCGCCACGA TGTCTCAAGA ACTTCACCAC CGGATTGATG CCGATGTGAT
```

FIG. 5F

```
3001  GAAGAACAGT ATTTGGTATC TGCGCTCTGC TGAAGCCAGT TACCTTCGGA AAAAGAGTTG
      CTTCTTGTCA TAAACCATAG ACGCGAGACG ACTTCGGTCA ATGGAAGCCT TTTTCTCAAC

3061  GTAGCTCTTG ATCCGGCAAA CAAACCACCG CTGGTAGCGG TGGTTTTTTT GTTTGCAAGC
      CATCGAGAAC TAGGCCGTTT GTTTGGTGGC GACCATCGCC ACCAAAAAAA CAAACGTTCG

3121  AGCAGATTAC GCGCAGAAAA AAAGGATCTC AAGAAGATCC TTTGATCTTT TCTACGGGGT
      TCGTCTAATG CGCGTCTTTT TTTCCTAGAG TTCTTCTAGG AAACTAGAAA AGATGCCCCA

                                                                PacI
                                                               ~~~~~~~~
3181  CTGACGCTCA GTGGAACGAA AACTCACGTT AAGGGATTTT GGTCATGGCT AGTTAATTAA
      GACTGCGAGT CACCTTGCTT TTGAGTGCAA TTCCCTAAAA CCAGTACCGA TCAATTAATT

           (SpAn→)
3241  GCTGCAATAA ACAATCATTA TTTTCATTGG ATCTGTGTGT TGGTTTTTTG TGTGGGCTTG
      CGACGTTATT TGTTAGTAAT AAAAGTAACC TAGACACACA ACCAAAAAAC ACACCCGAAC

3301  GGGGAGGGGG AGGCCAGAAT GACTCCAAGA GCTACAGGAA GGCAGGTCAG AGACCCCACT
      CCCCTCCCCC TCCGGTCTTA CTGAGGTTCT CGATGTCCTT CCGTCCAGTC TCTGGGGTGA

3361  GGACAAACAG TGGCTGGACT CTGCACCATA ACACACAATC AACAGGGGAG TGAGCTGGAT
      CCTGTTTGTC ACCGACCTGA GACGTGGTAT TGTGTGTTAG TTGTCCCCTC ACTCGACCTA

                    (hCMV-1Aprom→)
3421  CGAGCTAGAG TCCGTTACAT AACTTACGGT AAATGGCCCG CCTGGCTGAC CGCCCAACGA
      GCTCGATCTC AGGCAATGTA TTGAATGCCA TTTACCGGGC GGACCGACTG GCGGGTTGCT

3481  CCCCCGCCCA TTGACGTCAA TAATGACGTA TGTTCCCATA GTAACGCCAA TAGGGACTTT
      GGGGGCGGGT AACTGCAGTT ATTACTGCAT ACAAGGGTAT CATTGCGGTT ATCCCTGAAA

3541  CCATTGACGT CAATGGGTGG AGTATTTACG GTAAACTGCC CACTTGGCAG TACATCAAGT
      GGTAACTGCA GTTACCCACC TCATAAATGC CATTTGACGG GTGAACCGTC ATGTAGTTCA

3601  GTATCATATG CCAAGTACGC CCCCTATTGA CGTCAATGAC GGTAAATGGC CCGCCTGGCA
      CATAGTATAC GGTTCATGCG GGGGATAACT GCAGTTACTG CCATTTACCG GGCGGACCGT
```

FIG. 5G

```
3661  TTATGCCCAG TACATGACCT TATGGGACTT TCCTACTTGG CAGTACATCT ACGTATTAGT
      AATACGGGTC ATGTACTGGA ATACCCTGAA AGGATGAACC GTCATGTAGA TGCATAATCA

3721  CATCGCTATT ACCATGGTGA TGCGGTTTTG GCAGTACATC AATGGGCGTG GATAGCGGTT
      GTAGCGATAA TGGTACCACT ACGCCAAAAC CGTCATGTAG TTACCCGCAC CTATCGCCAA

3781  TGACTCACGG GGATTTCCAA GTCTCCACCC CATTGACGTC AATGGGAGTT TGTTTTGGCA
      ACTGAGTGCC CCTAAAGGTT CAGAGGTGGG GTAACTGCAG TTACCCTCAA ACAAAACCGT

3841  CCAAAATCAA CGGGACTTTC CAAAATGTCG TAACAACTCC GCCCCATTGA CGCAAATGGG
      GGTTTTAGTT GCCCTGAAAG GTTTTACAGC ATTGTTGAGG CGGGGTAACT GCGTTTACCC

3901  CGGTAGGCGT GTACGGTGGG AGGTCTATAT AAGCAGAGCT CGTTTAGTGA ACCGTCAGAT
      GCCATCCGCA CATGCCACCC TCCAGATATA TTCGTCTCGA GCAAATCACT TGGCAGTCTA

3961  CGCCTGGAGA CGCCATCCAC GCTGTTTTGA CCTCCATAGA AGACACCGGG ACCGATCCAG
      GCGGACCTCT GCGGTAGGTG CGACAAAACT GGAGGTATCT TCTGTGGCCC TGGCTAGGTC

4021  CCTCCGCGGC CGGGAACGGT GCATTGGAAC GCGGATTCCC CGTGCCAAGA GTGACGTAAG
      GGAGGCGCCG GCCCTTGCCA CGTAACCTTG CGCCTAAGGG GCACGGTTCT CACTGCATTC

4081  TACCGCCTAT AGAGTCTATA GGCCCACCTA GTTGTGACCG GCGCCTAGTG TTGACAATTA
      ATGGCGGATA TCTCAGATAT CCGGGTGGAT CAACACTGGC CGCGGATCAC AACTGTTAAT

4141  ATCATCGGCA TAGTATAATA CGACTCACTA TAGGAGGGCC ACCATGTCGA CTACTAACCT
      TAGTAGCCGT ATCATATTAT GCTGAGTGAT ATCCTCCCGG TGGTACAGCT GATGATTGGA

                                                    (HyTK→)
                                                     M  K   K  P  E  L
4201  TCTTCTCTTT CCTACAGCTG AGATCACCGG TAGGAGGGCC ATCATGAAAA AGCCTGAACT
      AGAAGAGAAA GGATGTCGAC TCTAGTGGCC ATCCTCCCGG TAGTACTTTT TCGGACTTGA

        T  A  T   S  V  A   K  F  L  I   E  K  F   D  S  V   S  D  L  M
4261  CACCGCGACG TCTGTCGCGA AGTTTCTGAT CGAAAAGTTC GACAGCGTCT CCGACCTGAT
      GTGGCGCTGC AGACAGCGCT TCAAAGACTA GCTTTTCAAG CTGTCGCAGA GGCTGGACTA
```

FIG. 5H

```
      Q  L  S   E  G  E   E  S  R  A   F  S  F   D  V  G   G  R  G  Y
4321  GCAGCTCTCG GAGGGCGAAG AATCTCGTGC TTTCAGCTTC GATGTAGGAG GGCGTGGATA
      CGTCGAGAGC CTCCCGCTTC TTAGAGCACG AAAGTCGAAG CTACATCCTC CCGCACCTAT

      V  L  R   V  N  S   C  A  D  G   F  Y  K   D  R  Y   V  Y  R  H
4381  TGTCCTGCGG GTAAATAGCT GCGCCGATGG TTTCTACAAA GATCGTTATG TTTATCGGCA
      ACAGGACGCC CATTTATCGA CGCGGCTACC AAAGATGTTT CTAGCAATAC AAATAGCCGT

      F  A  S   A  A  L   P  I  P  E   V  L  D   I  G  E   F  S  E  S
4441  CTTTGCATCG GCCGCGCTCC CGATTCCGGA AGTGCTTGAC ATTGGGGAAT TCAGCGAGAG
      GAAACGTAGC CGGCGCGAGG GCTAAGGCCT TCACGAACTG TAACCCCTTA AGTCGCTCTC

      L  T  Y   C  I  S   R  R  A  Q   G  V  T   L  Q  D   L  P  E  T
4501  CCTGACCTAT TGCATCTCCC GCCGTGCACA GGGTGTCACG TTGCAAGACC TGCCTGAAAC
      GGACTGGATA ACGTAGAGGG CGGCACGTGT CCCACAGTGC AACGTTCTGG ACGGACTTTG

      E  L  P   A  V  L   Q  P  V  A   E  L  M   D  A  I   A  A  A  D
4561  CGAACTGCCC GCTGTTCTGC AACCCGTCGC GGAGCTCATG GATGCGATCG CTGCGGCCGA
      GCTTGACGGG CGACAAGACG TTGGGCAGCG CCTCGAGTAC CTACGCTAGC GACGCCGGCT

      L  S  Q   T  S  G   F  G  P  F   G  P  Q   G  I  G   Q  Y  T  T
4621  TCTTAGCCAG ACGAGCGGGT TCGGCCCATT CGGACCGCAA GGAATCGGTC AATACACTAC
      AGAATCGGTC TGCTCGCCCA AGCCGGGTAA GCCTGGCGTT CCTTAGCCAG TTATGTGATG

      W  R  D   F  I  C   A  I  A  D   P  H  V   Y  H  W   Q  T  V  M
4681  ATGGCGTGAT TTCATATGCG CGATTGCTGA TCCCCATGTG TATCACTGGC AAACTGTGAT
      TACCGCACTA AAGTATACGC GCTAACGACT AGGGGTACAC ATAGTGACCG TTTGACACTA

      D  D  T   V  S  A   S  V  A  Q   A  L  D   E  L  M   L  W  A  E
4741  GGACGACACC GTCAGTGCGT CCGTCGCGCA GGCTCTCGAT GAGCTGATGC TTTGGGCCGA
      CCTGCTGTGG CAGTCACGCA GGCAGCGCGT CCGAGAGCTA CTCGACTACG AAACCCGGCT

      D  C  P   E  V  R   H  L  V  H   A  D  F   G  S  N   N  V  L  T
4801  GGACTGCCCC GAAGTCCGGC ACCTCGTGCA CGCGGATTTC GGCTCCAACA ATGTCCTGAC
      CCTGACGGGG CTTCAGGCCG TGGAGCACGT GCGCCTAAAG CCGAGGTTGT TACAGGACTG
```

FIG. 5I

```
       D  N  G  R  I  T  A  V  I  D  W  S  E  A  M  F  G  D  S  Q
4861   GGACAATGGC CGCATAACAG CGGTCATTGA CTGGAGCGAG GCGATGTTCG GGGATTCCCA
       CCTGTTACCG GCGTATTGTC GCCAGTAACT GACCTCGCTC CGCTACAAGC CCCTAAGGGT

       Y  E  V  A  N  I  F  F  W  R  P  W  L  A  C  M  E  Q  Q  T
4921   ATACGAGGTC GCCAACATCT TCTTCTGGAG GCCGTGGTTG GCTTGTATGG AGCAGCAGAC
       TATGCTCCAG CGGTTGTAGA AGAAGACCTC CGGCACCAAC CGAACATACC TCGTCGTCTG

       R  Y  F  E  R  R  H  P  E  L  A  G  S  P  R  L  R  A  Y  M
4981   GCGCTACTTC GAGCGGAGGC ATCCGGAGCT TGCAGGATCG CCGCGGCTCC GGGCGTATAT
       CGCGATGAAG CTCGCCTCCG TAGGCCTCGA ACGTCCTAGC GGCGCCGAGG CCCGCATATA

       L  R  I  G  L  D  Q  L  Y  Q  S  L  V  D  G  N  F  D  D  A
5041   GCTCCGCATT GGTCTTGACC AACTCTATCA GAGCTTGGTT GACGGCAATT TCGATGATGC
       CGAGGCGTAA CCAGAACTGG TTGAGATAGT CTCGAACCAA CTGCCGTTAA AGCTACTACG

       A  W  A  Q  G  R  C  D  A  I  V  R  S  G  A  G  T  V  G  R
5101   AGCTTGGGCG CAGGGTCGAT GCGACGCAAT CGTCCGATCC GGAGCCGGGA CTGTCGGGCG
       TCGAACCCGC GTCCCAGCTA CGCTGCGTTA GCAGGCTAGG CCTCGGCCCT GACAGCCCGC

       T  Q  I  A  R  R  S  A  A  V  W  T  D  G  C  V  E  V  A  S
5161   TACACAAATC GCCCGCAGAA GCGCGGCCGT CTGGACCGAT GGCTGTGTAG AAGTCGCGTC
       ATGTGTTTAG CGGGCGTCTT CGCGCCGGCA GACCTGGCTA CCGACACATC TTCAGCGCAG

       A  F  D  Q  A  A  R  S  R  G  H  S  N  R  R  T  A  L  R  P
5221   TGCGTTCGAC CAGGCTGCGC GTTCTCGCGG CCATAGCAAC CGACGTACGG CGTTGCGCCC
       ACGCAAGCTG GTCCGACGCG CAAGAGCGCC GGTATCGTTG GCTGCATGCC GCAACGCGGG

       R  R  Q  Q  E  A  T  E  V  R  P  E  Q  K  M  P  T  L  L  R
5281   TCGCCGGCAG CAAGAAGCCA CGGAAGTCCG CCCGGAGCAG AAAATGCCCA CGCTACTGCG
       AGCGGCCGTC GTTCTTCGGT GCCTTCAGGC GGGCCTCGTC TTTTACGGGT GCGATGACGC

       V  Y  I  D  G  P  H  G  M  G  K  T  T  T  T  Q  L  L  V  A
5341   GGTTTATATA GACGGTCCCC ACGGGATGGG GAAAACCACC ACCACGCAAC TGCTGGTGGC
       CCAAATATAT CTGCCAGGGG TGCCCTACCC CTTTTGGTGG TGGTGCGTTG ACGACCACCG
```

FIG. 5J

```
      L  G  S   R  D  D   I  V  Y  V   P  E  P   M  T  Y   W  R  V  L
5401  CCTGGGTTCG CGCGACGATA TCGTCTACGT ACCCGAGCCG ATGACTTACT GGCGGGTGCT
      GGACCCAAGC GCGCTGCTAT AGCAGATGCA TGGGCTCGGC TACTGAATGA CCGCCCACGA

      G  A  S   E  T  I   A  N  I  Y   T  T  Q   H  R  L   D  Q  G  E
5461  GGGGGCTTCC GAGACAATCG CGAACATCTA CACCACACAA CACCGCCTCG ACCAGGGTGA
      CCCCCGAAGG CTCTGTTAGC GCTTGTAGAT GTGGTGTGTT GTGGCGGAGC TGGTCCCACT

      I  S  A   G  D  A   A  V  V  M   T  S  A   Q  I  T   M  G  M  P
5521  GATATCGGCC GGGGACGCGG CGGTGGTAAT GACAAGCGCC CAGATAACAA TGGGCATGCC
      CTATAGCCGG CCCCTGCGCC GCCACCATTA CTGTTCGCGG GTCTATTGTT ACCCGTACGG

      Y  A  V   T  D  A   V  L  A  P   H  I  G   G  E  A   G  S  S  H
5581  TTATGCCGTG ACCGACGCCG TTCTGGCTCC TCATATCGGG GGGGAGGCTG GGAGCTCACA
      AATACGGCAC TGGCTGCGGC AAGACCGAGG AGTATAGCCC CCCCTCCGAC CCTCGAGTGT

      A  P  P   P  A  L   T  L  I  F   D  R  H   P  I  A   A  L  L  C
5641  TGCCCCGCCC CCGGCCCTCA CCCTCATCTT CGACCGCCAT CCCATCGCCG CCCTCCTGTG
      ACGGGGCGGG GGCCGGGAGT GGGAGTAGAA GCTGGCGGTA GGGTAGCGGC GGGAGGACAC

      Y  P  A   A  R  Y   L  M  G  S   M  T  P   Q  A  V   L  A  F  V
5701  CTACCCGGCC GCGCGGTACC TTATGGGCAG CATGACCCCC CAGGCCGTGC TGGCGTTCGT
      GATGGGCCGG CGCGCCATGG AATACCCGTC GTACTGGGGG GTCCGGCACG ACCGCAAGCA

      A  L  I   P  P  T   L  P  G  T   N  I  V   L  G  A   L  P  E  D
5761  GGCCCTCATC CCGCCGACCT TGCCCGGCAC CAACATCGTG CTTGGGGCCC TTCCGGAGGA
      CCGGGAGTAG GGCGGCTGGA ACGGGCCGTG GTTGTAGCAC GAACCCCGGG AAGGCCTCCT

      R  H  I   D  R  L   A  K  R  Q   R  P  G   E  R  L   D  L  A  M
5821  CAGACACATC GACCGCCTGG CCAAACGCCA GCGCCCCGGC GAGCGGCTGG ACCTGGCTAT
      GTCTGTGTAG CTGGCGGACC GGTTTGCGGT CGCGGGGCCG CTCGCCGACC TGGACCGATA

      L  A  A   I  R  R   V  Y  G  L   L  A  N   T  V  R   Y  L  Q  C
5881  GCTGGCTGCG ATTCGCCGCG TTTACGGGCT ACTTGCCAAT ACGGTGCGGT ATCTGCAGTG
      CGACCGACGC TAAGCGGCGC AAATGCCCGA TGAACGGTTA TGCCACGCCA TAGACGTCAC
```

FIG. 5K

```
          G   G   S   W   R   E   D   W   G   Q   L   S   G   T   A   V   P   P   Q   G
5941  CGGCGGGTCG TGGCGGGAGG ACTGGGGACA GCTTTCGGGG ACGGCCGTGC CGCCCCAGGG
      GCCGCCCAGC ACCGCCCTCC TGACCCCTGT CGAAAGCCCC TGCCGGCACG GCGGGGTCCC

          A   E   P   Q   S   N   A   G   P   R   P   H   I   G   D   T   L   F   T   L
6001  TGCCGAGCCC CAGAGCAACG CGGGCCCACG ACCCCATATC GGGGACACGT TATTTACCCT
      ACGGCTCGGG GTCTCGTTGC GCCCGGGTGC TGGGGTATAG CCCCTGTGCA ATAAATGGGA

          F   R   A   P   E   L   L   A   P   N   G   D   L   Y   N   V   F   A   W   A
6061  GTTTCGGGCC CCCGAGTTGC TGGCCCCCAA CGGCGACCTG TATAACGTGT TTGCCTGGGC
      CAAAGCCCGG GGGCTCAACG ACCGGGGGTT GCCGCTGGAC ATATTGCACA AACGGACCCG

          L   D   V   L   A   K   R   L   R   S   M   H   V   F   I   L   D   Y   D   Q
6121  CTTGGACGTC TTGGCCAAAC GCCTCCGTTC CATGCACGTC TTTATCCTGG ATTACGACCA
      GAACCTGCAG AACCGGTTTG CGGAGGCAAG GTACGTGCAG AAATAGGACC TAATGCTGGT

          S   P   A   G   C   R   D   A   L   L   Q   L   T   S   G   M   V   Q   T   H
6181  ATCGCCCGCC GGCTGCCGGG ACGCCCTGCT GCAACTTACC TCCGGGATGG TCCAGACCCA
      TAGCGGGCGG CCGACGGCCC TGCGGGACGA CGTTGAATGG AGGCCCTACC AGGTCTGGGT

          V   T   T   P   G   S   I   P   T   I   C   D   L   A   R   T   F   A   R   E
6241  CGTCACCACC CCCGGCTCCA TACCGACGAT ATGCGACCTG GCGCGCACGT TTGCCCGGGA
      GCAGTGGTGG GGGCCGAGGT ATGGCTGCTA TACGCTGGAC CGCGCGTGCA AACGGGCCCT

          M   G   E   A   N   *   (BGh pAn→)
6301  GATGGGGGAG GCTAACTGAG TCGAGAATTC GCTAGAGGGC CCTATTCTAT AGTGTCACCT
      CTACCCCCTC CGATTGACTC AGCTCTTAAG CGATCTCCCG GGATAAGATA TCACAGTGGA

6361  AAATGCTAGA GCTCGCTGAT CAGCCTCGAC TGTGCCTTCT AGTTGCCAGC CATCTGTTGT
      TTTACGATCT CGAGCGACTA GTCGGAGCTG ACACGGAAGA TCAACGGTCG GTAGACAACA

6421  TTGCCCCTCC CCCGTGCCTT CCTTGACCCT GGAAGGTGCC ACTCCCACTG TCCTTTCCTA
      AACGGGGAGG GGGCACGGAA GGAACTGGGA CCTTCCACGG TGAGGGTGAC AGGAAAGGAT

6481  ATAAAATGAG GAAATTGCAT CGCATTGTCT GAGTAGGTGT CATTCTATTC TGGGGGGTGG
      TATTTTACTC CTTTAACGTA GCGTAACAGA CTCATCCACA GTAAGATAAG ACCCCCCACC
```

FIG. 5L

6541 GGTGGGGCAG GACAGCAAGG GGGAGGATTG GGAAGACAAT AGCAGGCATG CGCAGGGCCC
CCACCCCGTC CTGTCGTTCC CCCTCCTAAC CCTTCTGTTA TCGTCCGTAC GCGTCCCGGG

6601 AATTGCTCGA GCGGCCGCAA TAAAATATCT TTATTTTCAT TACATCTGTG TGTTGGTTTT
TTAACGAGCT CGCCGGCGTT ATTTTATAGA AATAAAAGTA ATGTAGACAC ACAACCAAAA

6661 TTGTGTGAAT CGTAACTAAC ATACGCTCTC CATCAAAACA AAACGAAACA AAACAAACTA
AACACACTTA GCATTGATTG TATGCGAGAG GTAGTTTTGT TTTGCTTTGT TTTGTTTGAT

6721 GCAAAATAGG CTGTCCCCAG TGCAAGTGCA GGTGCCAGAA CATTTCTCTA (SEQ ID NO:13)
CGTTTTATCC GACAGGGGTC ACGTTCACGT CCACGGTCTT GTAAAGAGAT (SEQ ID NO:14)

IL13zetakine amino acid sequence (SEQ ID NO:15).
HyTK amino acid sequence (SEQ ID NO:16).

FIG. 6

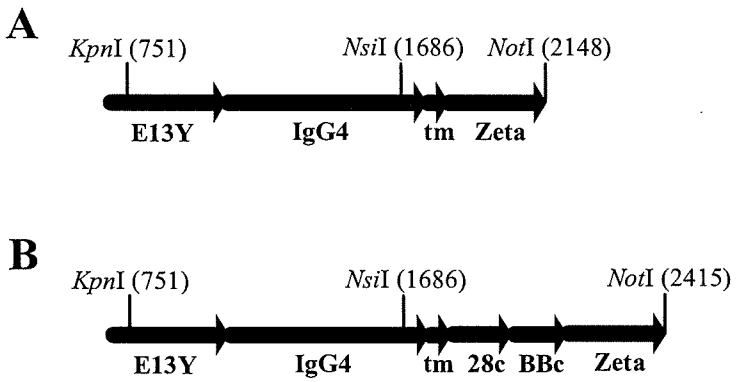

A
KpnI (751)
NsiI (1686)
NotI (2148)
E13Y
IgG4
tm
Zeta
B
KpnI (751)
NsiI (1686)
NotI (2415)
E13Y
IgG4
tm
28c
BBc
Zeta

FIG. 7

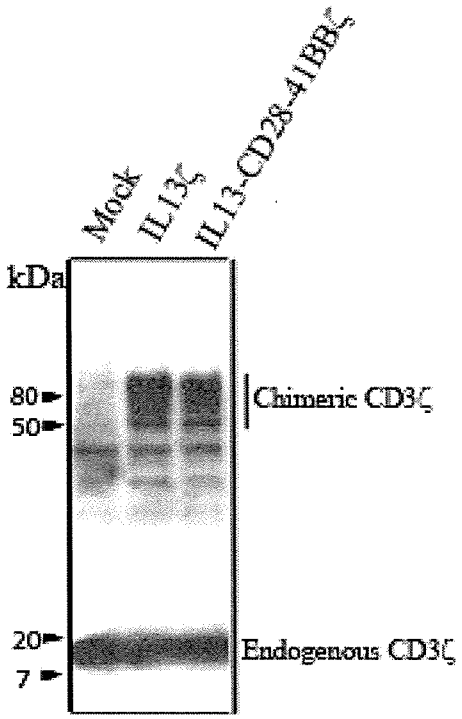

Mock
IL13ζ
IL13-CD28-41BBζ
kDa
80
50
20
7
Chimeric CD3ζ
Endogenous CD3ζ

FIG. 8

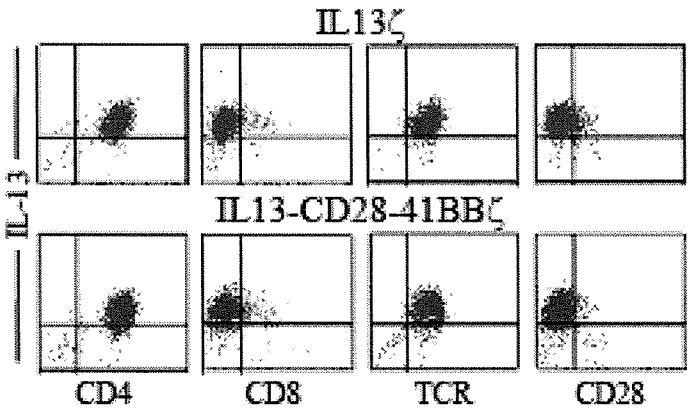


FIG. 9

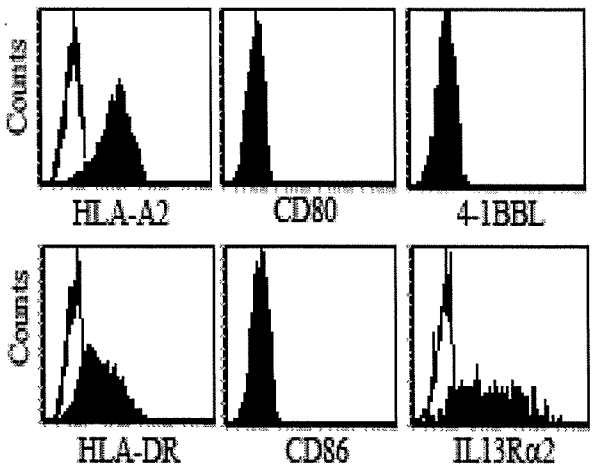


FIG. 10

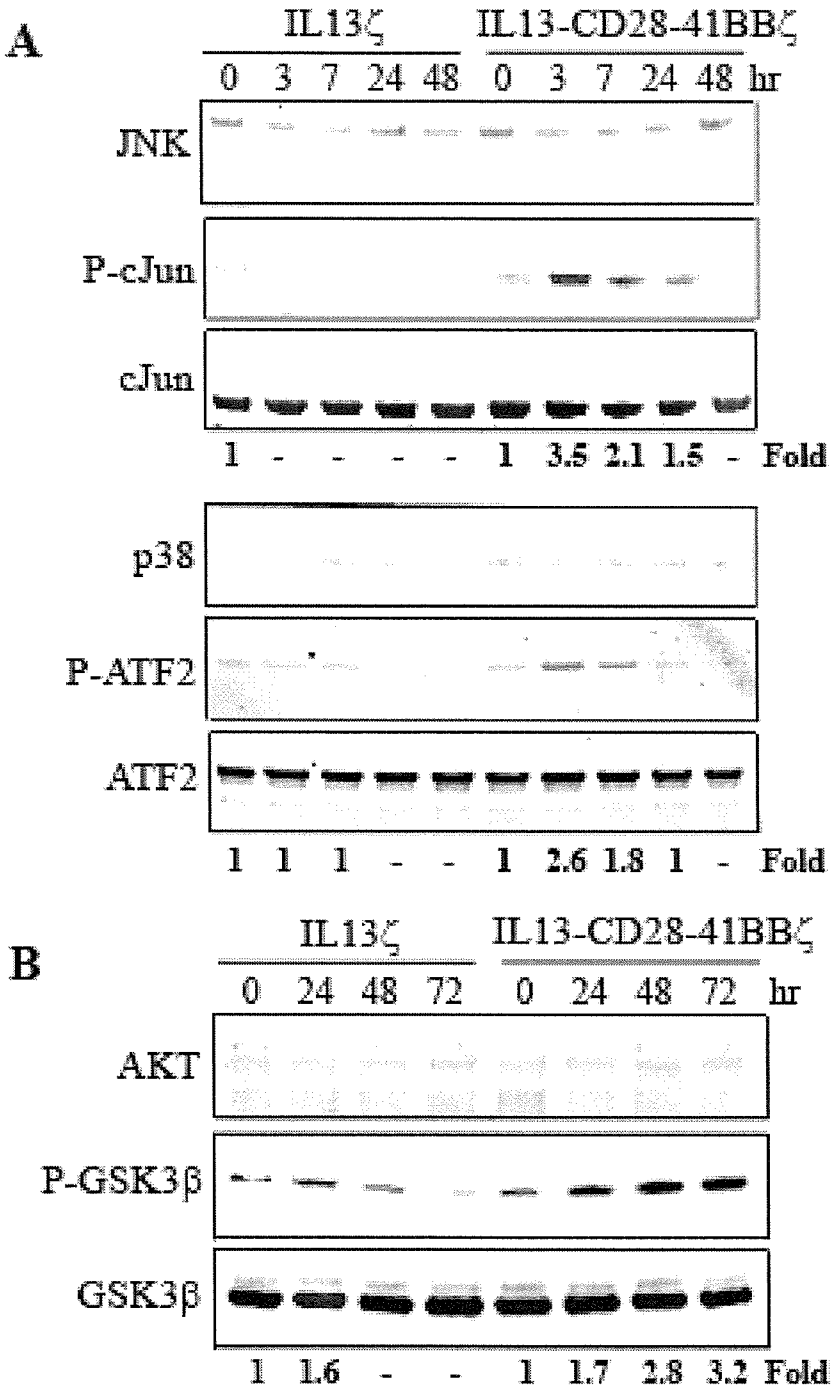

A
IL13ζ
IL13-CD28-41BBζ
0 3 7 24 48 0 3 7 24 48 hr
JNK
P-cJun
cJun
1 - - - - 1 3.5 2.1 1.5 - Fold
p38
P-ATF2
ATF2
1 1 1 - - 1 2.6 1.8 1 - Fold
B
IL13ζ
IL13-CD28-41BBζ
0 24 48 72 0 24 48 72 hr
AKT
P-GSK3β
GSK3β
1 1.6 - - 1 1.7 2.8 3.2 Fold

FIG. 11

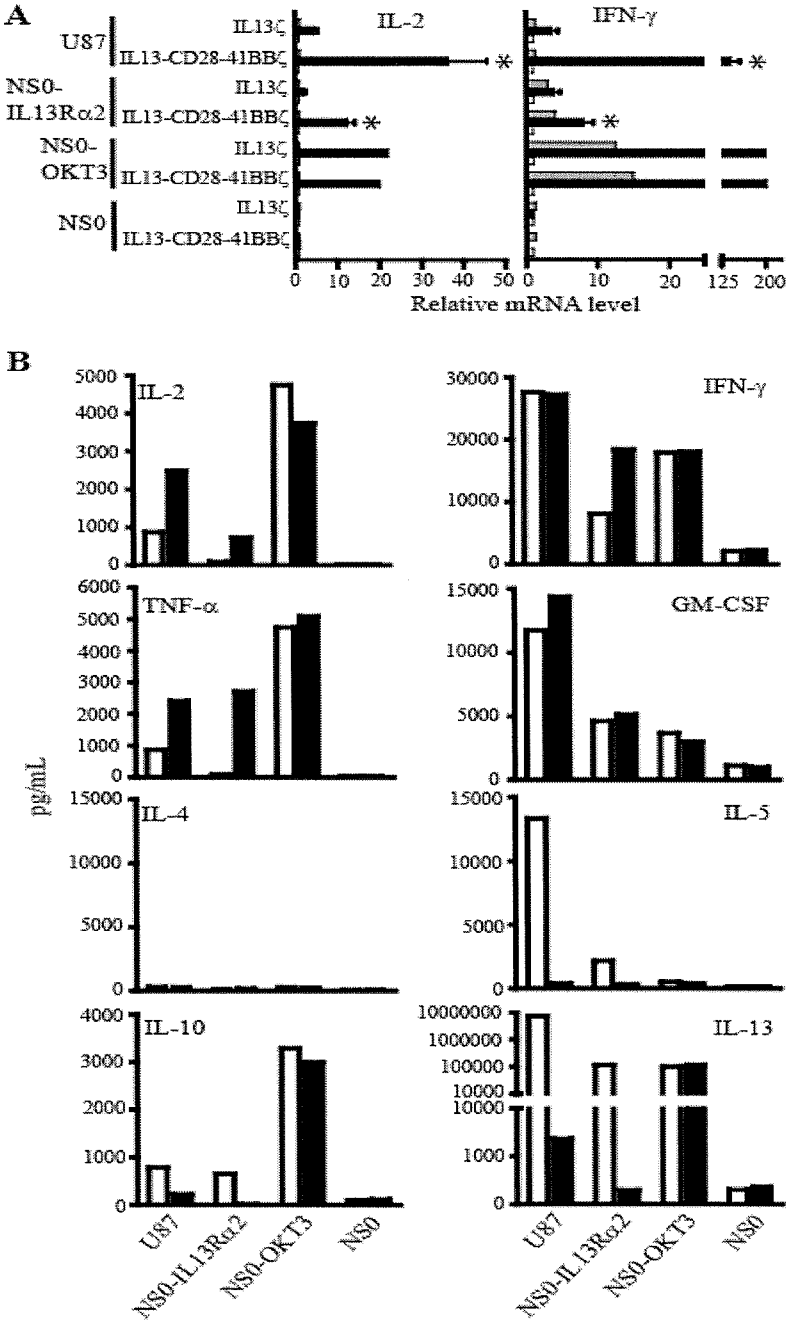

A
U87
NS0-IL13Rα2
NS0-OKT3
NS0
IL13ζ
IL13-CD28-41BBζ
IL-2
IFN-γ
0 10 20 30 40 50
0 10 20 125 200
Relative mRNA level
B
IL-2
IFN-γ
TNF-α
GM-CSF
IL-4
IL-5
IL-10
IL-13
pg/mL
U87
NS0-IL13Rα2
NS0-OKT3
NS0

FIG. 12

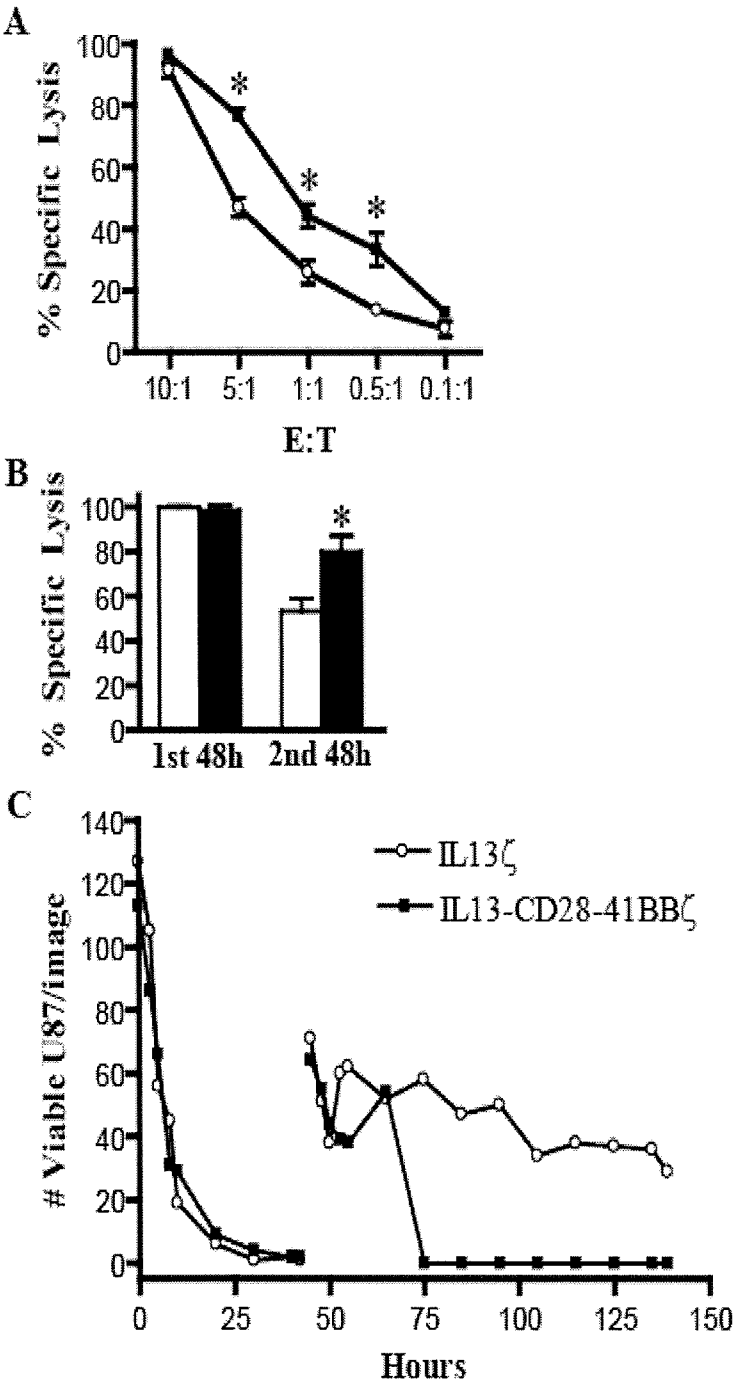

A
% Specific Lysis
100
80
60
40
20
0
*
*
*
10:1
5:1
1:1
0.5:1
0.1:1
E:T
B
% Specific Lysis
100
80
60
40
20
0
*
1st 48h
2nd 48h
C
Viable U87/image
140
120
100
80
60
40
20
0
IL13ζ
IL13-CD28-41BBζ
0
25
50
75
100
125
150
Hours

FIG. 13

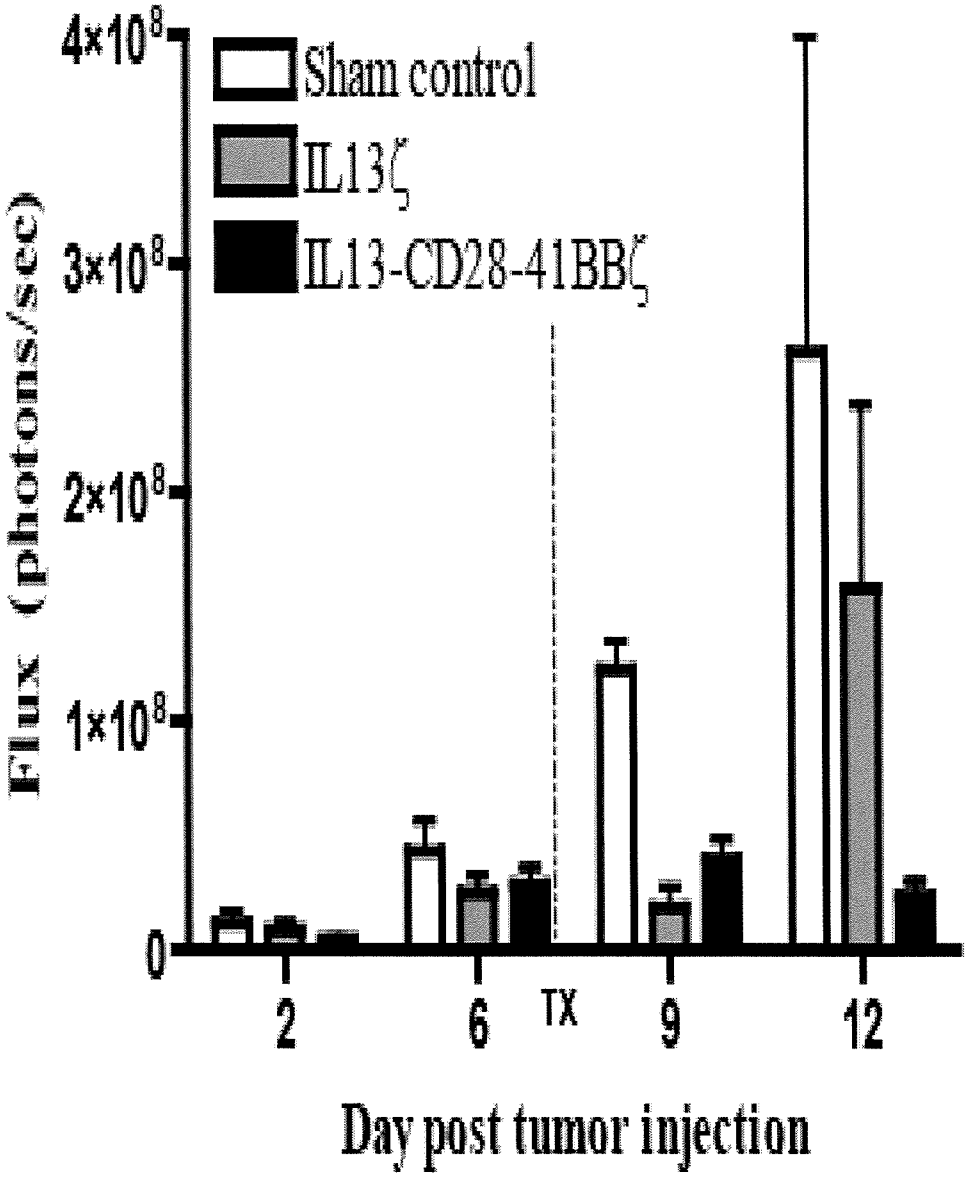

4×10^8
3×10^8
2×10^8
1×10^8
0
Flux (photons/sec)
Sham control
IL13ζ
IL13-CD28-41BBζ
2
6
TX
9
12
Day post tumor injection

FIG. 14

ATGCTGCTGC TGGTGACCAG
CCTGCTGCTG TGCGAGCTGC CCCACCCCGC CTTTCTGCTG ATCCCTGGCC CCGTGCCCCC
TAGCACCGCC CTGCGCTACC TGATCGAGGA ACTGGTGAAC ATCACCCAGA ACCAGAAAGC
CCCCCTGTGC AACGGCAGCA TGGTGTGGAG CATCAACCTG ACCGCCGGCA TGTACTGTGC
CGCCCTGGAA AGCCTGATCA ACGTGAGCGG CTGCAGCGCC ATCGAGAAAA CCCAGCGGAT
GCTGTCCGGC TTCTGCCCCC ACAAGGTGTC CGCCGGACAG TTCAGCAGCC TGCACGTGCG
GGACACCAAG ATCGAGGTGG CCCAGTTCGT GAAGGACCTG CTGCTGCACC TGAAGAAGCT
GTTCCGGGAG GGCCGGTTCA ACGAGAGCAA GTACGGCCCT CCCTGCCCCC CTTGCCCTGC
CCCAGAGTTC CTGGGCGGAC CCAGCGTGTT CCTGTTCCCC CCCAAGCCCA AGGACACCCT
GATGATCAGC CGGACCCCTG AGGTGACCTG CGTGGTGGTG GACGTGAGCC AGGAAGATCC
TGAGGTCCAG TTCAATTGGT ACGTGGACGG CGTGGAAGTG CACAACGCCA AGACCAAGCC
CAGAGAGGAA CAGTTCAACA GCACCTACCG GGTGGTGTCT GTGCTGACCG TGCTGCACCA
GGACTGGCTG AACGGCAAAG AATACAAGTG CAAGGTGTCC AACAAGGGCC TGCCCAGCAG
CATCGAAAAG ACCATCAGCA AGGCCAAGGG CCAGCCTCGC GAGCCCCAGG TGTACACCCT
GCCTCCCTCC CAGGAAGAGA TGACCAAGAA CCAGGTGTCC CTGACCTGCC TGGTGAAGGG
CTTCTACCCC AGCGACATCG CCGTGGAGTG GGAGAGCAAC GGCCAGCCTG AGAACAACTA
CAAGACCACC CCTCCCGTGC TGGACAGCGA CGGCAGCTTC TTCCTGTACA GCCGGCTGAC
CGTGGACAAG AGCCGGTGGC AGGAAGGCAA CGTCTTTAGC TGCAGCGTGA TGCACGAGGC
CCTGCACAAC CACTACACCC AGAAGAGCCT GAGCCTGTCC CTGGGCAAGA TGTTCTGGGT
GCTGGTGGTG GTGGGCGGGG TGCTGGCCTG CTACAGCCTG CTGGTGACAG TGGCCTTCAT
CATCTTTTGG GTGCGGAGCA AGCGGAGCAG AGGCGGCCAC AGCGACTACA TGAACATGAC
CCCCAGACGG CCTGGCCCCA CCCGGAAGCA CTACCAGCCC TACGCCCCAC CCAGGGACTT
TGCCGCCTAC CGGTCCGGCG GAGGGCGGGT GAAGTTCAGC AGAAGCGCCG ACGCCCCTGC
CTACCAGCAG GGCCAGAATC AGCTGTACAA CGAGCTGAAC CTGGGCAGAA GGGAAGAGTA
CGACGTCCTG GATAAGCGGA GAGGCCGGGA CCCTGAGATG GGCGGCAAGC CTCGGCGGAA
GAACCCCCAG GAAGGCCTGT ATAACGAACT GCAGAAAGAC AAGATGGCCG AGGCCTACAG
CGAGATCGGC ATGAAGGGCG AGCGGAGGCG GGGCAAGGGC CACGACGGCC TGTATCAGGG
CCTGTCCACC GCCACCAAGG ATACCTACGA CGCCCTGCAC ATGCAGGCCC TGCCCCCAAG
GTGA (SEQ ID NO:36)

FIG. 15

ATGCT TCTCCTGGTG ACAAGCCTTC TGCTCTGTGA GTTACCACAC
CCAGCATTCC TCCTGATCCC AGGCCCTGTG CCTCCCTCTA CAGCCCTCAG GGAGCTCATT
GAGGAGCTGG TCAACATCAC CCAGAACCAG AAGGCTCCGC TCTGCAATGG CAGCATGGTA
TGGAGCATCA ACCTGACAGC TGGCATGTAC TGTGCAGCCC TGGAATCCCT GATCAACGTG
TCAGGCTGCA GTGCCATCGA GAAGACCCAG AGGATGCTGA GCGGATTCTG CCCGCACAAG
GTCTCAGCTG GGCAGTTTTC CAGCTTGCAT GTCCGAGACA CCAAAATCGA GGTGGCCCAG
TTTGTAAAGG ACCTGCTCTT ACATTTAAAG AAACTTTTTC GCGAGGGACG GTTCAACGAG
TCCAAATATG GTCCCCCATG CCCACCATGC CCAGCACCTG AGTTCCTGGG GGGACCATCA
GTCTTCCTGT TCCCCCCAAA ACCCAAGGAC ACTCTCATGA TCTCCCGGAC CCCTGAGGTC
ACGTGCGTGG TGGTGGACGT GAGCCAGGAA GACCCCGAGG TCCAGTTCAA CTGGTACGTG
GATGGCGTGG AGGTGCATAA TGCCAAGACA AAGCCGCGGG AGGAGCAGTT CAACAGCACG
TACCGTGTGG TCAGCGTCCT CACCGTCCTG CACCAGGACT GGCTGAACGG CAAGGAGTAC
AAGTGCAAGG TCTCCAACAA AGGCCTCCCG TCCTCCATCG AGAAAACCAT CTCCAAAGCC
AAAGGGCAGC CCCGAGAGCC ACAGGTGTAC ACCCTGCCCC CATCCCAGGA GGAGATGACC
AAGAACCAGG TCAGCCTGAC CTGCCTGGTC AAAGGCTTCT ACCCCAGCGA CATCGCCGTG
GAGTGGGAGA GCAATGGGCA GCCGGAGAAC AACTACAAGA CCACGCCTCC CGTGCTGGAC
TCCGACGGCT CCTTCTTCCT CTACAGCAGG CTAACCGTGG ACAAGAGCAG GTGGCAGGAG
GGGAATGTCT TCTCATGCTC CGTGATGCAT GAGGCTCTGC ACAACCACTA CACACAGAAG
AGCCTCTCCC TGTCTCTGGG TAAAATGGCC CTGATTGTGC TGGGGGGCGT CGCCGGCCTC
CTGCTTTTCA TTGGGCTAGG CATCTTCTTC AGGAGTAAGA GGAGCAGGCT CCTGCACAGT
GACTACATGA ACATGACTCC CCGCCGCCCT GGGCCCACCC GCAAGCATTA CCAGCCCTAT
GCCCCACCAC GCGACTTCGC AGCCTATCGC TCCGGAGGTG GC**AAACGGGG CAGAAAGAAA**
CTCCTGTATA TATTCAAACA ACCATTTATG AGACCAGTAC AAACTACTCA AGAGGAAGAT
GGCTGTAGCT GCCGATTTCC AGAAGAAGAA GAAGGAGGAT GTGAACTGGG AGGTGGCAGA
GTGAAGTTCA GCAGGAGCGC AGACGCCCCC GCGTACCAGC AGGGCCAGAA CCAGCTCTAT
AACGAGCTCA ATCTAGGACG AAGAGAGGAG TACGATGTTT TGGACAAGAG ACGTGGCCGG
GACCCTGAGA TGGGGGGAAA GCCGAGAAGG AAGAACCCTC AGGAAGGCCT GTACAATGAA
CTGCAGAAAG ATAAGATGGC GGAGGCCTAC AGTGAGATTG GGATGAAAGG CGAGCGCCGG
AGGGGCAAGG GGCACGATGG CCTTTACCAG GGTCTCAGTA CAGCCACCAA GGACACCTAC
GACGCCCTTC ACATGCAGGC CCTGCCCCCT CGCTGA (SEQ ID NO:37)

FIG. 16

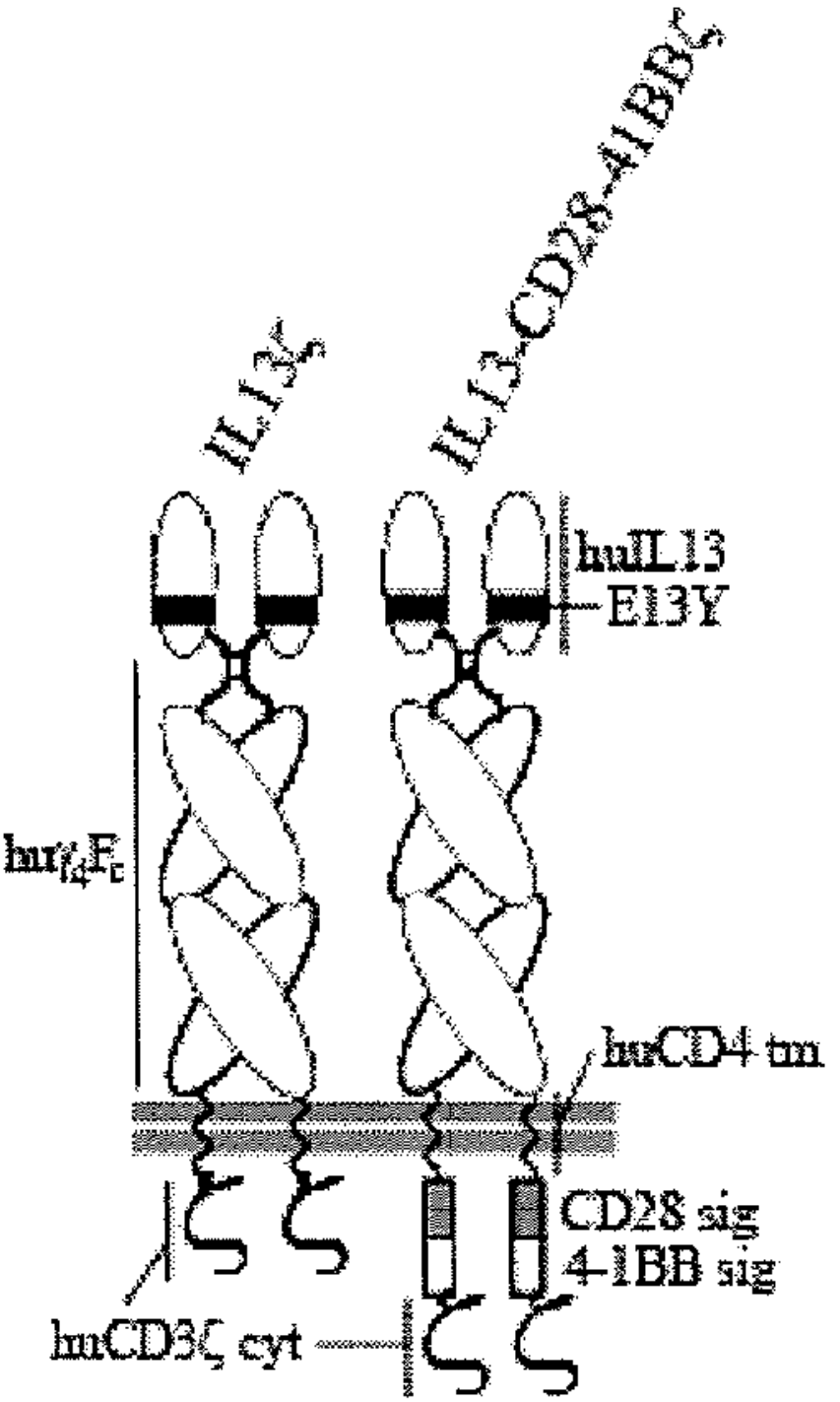
AT GCTTCTCCTG GTGACAAGCC TTCTGCTCTG TGAGTTACCA
CACCCAGCAT TCCTCCTGAT CCCAGGCCCT GTGCCTCCCT CTACAGCCCT CAGGTACCTC
ATTGAGGAGC TGGTCAACAT CACCCAGAAC CAGAAGGCTC CGCTCTGCAA TGGCAGCATG
GTATGGAGCA TCAACCTGAC AGCTGGCATG TACTGTGCAG CCCTGGAATC CCTGATCAAC
GTGTCAGGCT GCAGTGCCAT CGAGAAGACC CAGAGGATGC TGAGCGGATT CTGCCCGCAC
AAGGTCTCAG CTGGGCAGTT TTCCAGCTTG CATGTCCGAG ACACCAAAAT CGAGGTGGCC
CAGTTTGTAA AGGACCTGCT CTTACATTTA AAGAAACTTT TTCGCGAGGG ACGGTTCAAC
GAGTCCAAAT ATGGTCCCCC ATGCCCACCA TGCCCAGCAC CTGAGTTCCT GGGGGGACCA
TCAGTCTTCC TGTTCCCCCC AAAACCCAAG GACACTCTCA TGATCTCCCG GACCCCTGAG
GTCACGTGCG TGGTGGTGGA CGTGAGCCAG GAAGACCCCG AGGTCCAGTT CAACTGGTAC
GTGGATGGCG TGGAGGTGCA TAATGCCAAG ACAAAGCCGC GGGAGGAGCA GTTCAACAGC
ACGTACCGTG TGGTCAGCGT CCTCACCGTC CTGCACCAGG ACTGGCTGAA CGGCAAGGAG
TACAAGTGCA AGGTCTCCAA CAAAGGCCTC CCGTCCTCCA TCGAGAAAAC CATCTCCAAA
GCCAAAGGGC AGCCCCGAGA GCCACAGGTG TACACCCTGC CCCCATCCCA GGAGGAGATG
ACCAAGAACC AGGTCAGCCT GACCTGCCTG GTCAAAGGCT TCTACCCCAG CGACATCGCC
GTGGAGTGGG AGAGCAATGG GCAGCCGGAG AACAACTACA AGACCACGCC TCCCGTGCTG
GACTCCGACG GCTCCTTCTT CCTCTACAGC AGGCTAACCG TGGACAAGAG CAGGTGGCAG
GAGGGGAATG TCTTCTCATG CTCCGTGATG CATGAGGCTC TGCACAACCA CTACACACAG
AAGAGCCTCT CCCTGTCCCT AGGTAAATTT TGGGTGCTGG TGGTGGTTGG TGGAGTCCTG
GCTTGCTATA GCTTGCTAGT AACAGTGGCC TTTATTATTT TCTGGGTG*AG GAGTAAGAGG*
AGCAGGCTCC TGCACAGTGA CTACATGAAC ATGACTCCCC GCCGCCCCGG GCCCACCCGC
*AAGCATTACC AGCCCTATGC CCCACCACGC GACTTCGCAG CCTATCGCTC C***AGGGACCAG**
AGGCTGCCCC CCGATGCCCA CAAGCCCCCT GGGGGAGGCA GTTTCCGGAC CCCCATCCAA
GAGGAGCAGG CCGACGCCCA CTCCACCCTG GCCAAGATC*A GAGTGAAGTT CAGCAGGAGC*
GCAGACGCCC CCGCGTACCA GCAGGGCCAG AACCAGCTCT ATAACGAGCT CAATCTAGGA
CGAAGAGAGG AGTACGATGT TTTGGACAAG AGACGTGGCC GGGACCCTGA GATGGGGGGA
AAGCCGAGAA GGAAGAACCC TCAGGAAGGC CTGTACAATG AACTGCAGAA AGATAAGATG
GCGGAGGCCT ACAGTGAGAT TGGGATGAAA GGCGAGCGCC GGAGGGGCAA GGGGCACGAT
GGCCTTTACC AGGGTCTCAG TACAGCCACC AAGGACACCT ACGACGCCCT TCACATGCAG
GCCCTGCCCC CTCGCTGA (SEQ ID NO:38)

FIG. 17

ATGCTTCTCC TGGTGACAAG CCTTCTGCTC TGTGAGTTAC CACACCCAGC ATTCCTCCTG
ATCCCAGGCC CTGTGCCTCC CTCTACAGCC CTCAGGTACC TCATTGAGGA GCTGGTCAAC
ATCACCCAGA ACCAGAAGGC TCCGCTCTGC AATGGCAGCA TGGTATGGAG CATCAACCTG
ACAGCTGGCA TGTACTGTGC AGCCCTGGAA TCCCTGATCA ACGTGTCAGG CTGCAGTGCC
ATCGAGAAGA CCCAGAGGAT GCTGAGCGGA TTCTGCCCGC ACAAGGTCTC AGCTGGGCAG
TTTTCCAGCT TGCATGTCCG AGACACCAAA ATCGAGGTGG CCCAGTTTGT AAAGGACCTG
CTCTTACATT TAAAGAAACT TTTTCGCGAG GGACGGTTCA ACGAGTCCAA ATATGGTCCC
CCATGCCCAC CATGCCCAGC ACCTGAGTTC CTGGGGGGAC CATCAGTCTT CCTGTTCCCC
CCAAAACCCA AGGACACTCT CATGATCTCC CGGACCCCTG AGGTCACGTG CGTGGTGGTG
GACGTGAGCC AGGAAGACCC CGAGGTCCAG TTCAACTGGT ACGTGGATGG CGTGGAGGTG
CATAATGCCA AGACAAAGCC GCGGGAGGAG CAGTTCAACA GCACGTACCG TGTGGTCAGC
GTCCTCACCG TCCTGCACCA GGACTGGCTG AACGGCAAGG AGTACAAGTG CAAGGTCTCC
AACAAAGGCC TCCCGTCCTC CATCGAGAAA ACCATCTCCA AAGCCAAAGG GCAGCCCCGA
GAGCCACAGG TGTACACCCT GCCCCCATCC CAGGAGGAGA TGACCAAGAA CCAGGTCAGC
CTGACCTGCC TGGTCAAAGG CTTCTACCCC AGCGACATCG CCGTGGAGTG GGAGAGCAAT
GGGCAGCCGG AGAACAACTA CAAGACCACG CCTCCCGTGC TGGACTCCGA CGGCTCCTTC
TTCCTCTACA GCAGGCTAAC CGTGGACAAG AGCAGGTGGC AGGAGGGGAA TGTCTTCTCA
TGCTCCGTGA TGCATGAGGC TCTGCACAAC CACTACACAC AGAAGAGCCT CTCCCTGTCC
CTAGGTAAAA TGTTTTGGGT GCTGGTGGTG GTTGGTGGAG TCCTGGCTTG CTATAGCTTG
CTAGTAACAG TGGCCTTTAT TATTTTCTGG GTGAGGAGTA AGAGGAGCAG GGGCGGACAC
AGTGACTACA TGAACATGAC TCCCCGCCGC CCTGGGCCCA CCCGCAAGCA TTACCAGCCC
TATGCCCCAC CACGCGACTT CGCAGCCTAT CGCTCCGGAG GTGGC**AAACG GGGCAGAAAG**
AAACTCCTGT ATATATTCAA ACAACCATTT ATGAGACCAG TACAAACTAC TCAAGAGGAA
GATGGCTGTA GCTGCCGATT TCCAGAAGAA GAAGAAGGAG GATGTGAACT GGGAGGTGGC
AGAGTGAAGT TCAGCAGGAG CGCAGACGCC CCCGCGTACC AGCAGGGCCA GAACCAGCTC
TATAACGAGC TCAATCTAGG ACGAAGAGAG GAGTACGATG TTTTGGACAA GAGACGTGGC
CGGGACCCTG AGATGGGGGG AAAGCCGAGA AGGAAGAACC CTCAGGAAGG CCTGTACAAT
GAACTGCAGA AAGATAAGAT GGCGGAGGCC TACAGTGAGA TTGGGATGAA AGGCGAGCGC
CGGAGGGGCA AGGGGCACGA TGGCCTTTAC CAGGGTCTCA GTACAGCCAC CAAGGACACC
TACGACGCCC TTCACATGCA GGCCCTGCCC CCTCGCTGA (SEQ ID NO:39)

FIG. 18

ATGCTTCTCC TGGTGACAAG CCTTCTGCTC
TGTGAGTTAC CACACCCAGC ATTCCTCCTG ATCCCAGGCC CTGTGCCTCC CTCTACAGCC
CTCAGGTACC TCATTGAGGA GCTGGTCAAC ATCACCCAGA ACCAGAAGGC TCCGCTCTGC
AATGGCAGCA TGGTATGGAG CATCAACCTG ACAGCTGGCA TGTACTGTGC AGCCCTGGAA
TCCCTGATCA ACGTGTCAGG CTGCAGTGCC ATCGAGAAGA CCCAGAGGAT GCTGAGCGGA
TTCTGCCCGC ACAAGGTCTC AGCTGGGCAG TTTTCCAGCT TGCATGTCCG AGACACCAAA
ATCGAGGTGG CCCAGTTTGT AAAGGACCTG CTCTTACATT TAAAGAAACT TTTTCGCGAG
GGACGGTTCA ACGAGTCCAA ATATGGTCCC CCATGCCCAC CATGCCCAGC ACCTGAGTTC
CTGGGGGGAC CATCAGTCTT CCTGTTCCCC CCAAAACCCA AGGACACTCT CATGATCTCC
CGGACCCCTG AGGTCACGTG CGTGGTGGTG GACGTGAGCC AGGAAGACCC CGAGGTCCAG
TTCAACTGGT ACGTGGATGG CGTGGAGGTG CATAATGCCA AGACAAAGCC GCGGGAGGAG
CAGTTCAACA GCACGTACCG TGTGGTCAGC GTCCTCACCG TCCTGCACCA GGACTGGCTG
AACGGCAAGG AGTACAAGTG CAAGGTCTCC AACAAAGGCC TCCCGTCCTC CATCGAGAAA
ACCATCTCCA AAGCCAAAGG GCAGCCCCGA GAGCCACAGG TGTACACCCT GCCCCCATCC
CAGGAGGAGA TGACCAAGAA CCAGGTCAGC CTGACCTGCC TGGTCAAAGG CTTCTACCCC
AGCGACATCG CCGTGGAGTG GGAGAGCAAT GGGCAGCCGG AGAACAACTA CAAGACCACG
CCTCCCGTGC TGGACTCCGA CGGCTCCTTC TTCCTCTACA GCAGGCTAAC CGTGGACAAG
AGCAGGTGGC AGGAGGGGAA TGTCTTCTCA TGCTCCGTGA TGCATGAGGC TCTGCACAAC
CACTACACAC AGAAGAGCCT CTCCCTGTCC CTAGGTAAAA TGTTTTGGGT GCTGGTGGTG
GTTGGTGGAG TCCTGGCTTG CTATAGCTTG CTAGTAACAG TGGCCTTTAT TATTTTCTGG
GTGAGGAGTA AGAGGAGCAG GGGCGGACAC AGTGACTACA TGAACATGAC TCCCCGCCGC
CCTGGGCCCA CCCGCAAGCA TTACCAGCCC TATGCCCCAC CACGCGACTT CGCAGCCGGA
GGTGGCGGAG GTGGC**AAACG GGGCAGAAAG AAACTCCTGT ATATATTCAA ACAACCATTT**
ATGAGACCAG TACAAACTAC TCAAGAGGAA GATGGCTGTA GCTGCCGATT TCCAGAAGAA
GAAGAAGGAG GATGTGAACT GGGAGGTGGC AGAGTGAAGT TCAGCAGGAG CGCAGACGCC
CCCGCGTACC AGCAGGGCCA GAACCAGCTC TATAACGAGC TCAATCTAGG ACGAAGAGAG
GAGTACGATG TTTTGGACAA GAGACGTGGC CGGGACCCTG AGATGGGGGG AAAGCCGAGA
AGGAAGAACC CTCAGGAAGG CCTGTACAAT GAACTGCAGA AAGATAAGAT GGCGGAGGCC
TACAGTGAGA TTGGGATGAA AGGCGAGCGC CGGAGGGGCA AGGGGCACGA TGGCCTTTAC
CAGGGTCTCA GTACAGCCAC CAAGGACACC TACGACGCCC TTCACATGCA GGCCCTGCCC
CCTCGCTGA (SEQ ID NO:40)


IL13ζ
IL13-CD28-4IBBζ
huIL13
E13Y
huγ4Fc
huCD4 tm
CD28 sig
4-1BB sig
huCD3ζ cyt