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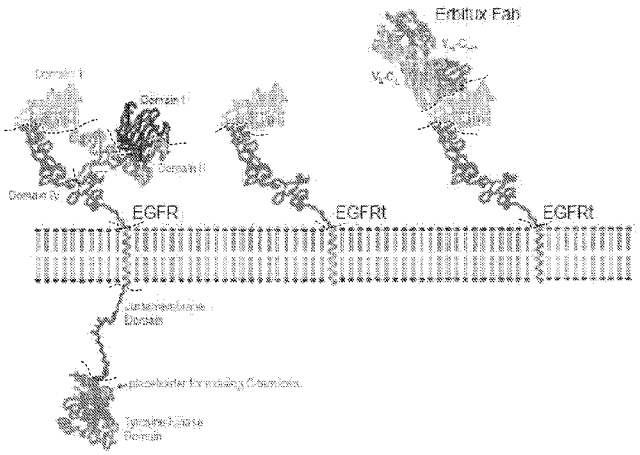
Figure 1



(57) Abstract: A non-immunogenic selection epitope may be generated by removing certain amino acid sequences of the protein. For example, a gene encoding a truncated human epidermal growth factor receptor polypeptide (EGFRt) that lacks the membrane distal EGF-binding domain and the cytoplasmic signaling tail, but retains an extracellular epitope recognized by an anti-EGFR antibody is provided. Cells may be genetically modified to express EGFRt and then purified without the immunoactivity that would accompany the use of full-length EGFR immunoactivity. Through flow cytometric analysis, EGFRt was successfully utilized as an in vivo tracking marker for genetically modified human T cell engraftment in mice. Furthermore, EGFRt was demonstrated to have cellular depletion potential through cetuximab mediated antibody dependent cellular cytotoxicity (ADCC) pathways. Thus, EGFRt may be used as a non-immunogenic selection tool, tracking marker, a depletion tool or a suicide gene for genetically modified cells having therapeutic potential.

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TRUNCATED EPIDERIMAL GROWTH FACTOR RECEPTOR (EGFRt) FOR TRANSDUCED T CELL SELECTION

PRIORITY CLAIM

[0001] This application claims the benefit of U.S. Provisional Application No. 61/257,567, filed November 3, 2009, the subject matter of which is incorporated by reference as if fully set forth herein.

TECHNICAL FIELD

[0002] The present products and methods relate to the fields of immunology and purification of genetically modified cells, specifically to a truncated or otherwise modified receptor paired with a corresponding antibody, such as a polypeptide derived from human epidermal growth factor receptor (EGFR) paired with cetuximab, for use in cancer immunotherapy.

BACKGROUND

[0003] Immune cell products with homogenous expression of tumor targeting chimeric antigen receptors (CARs) are desirable for clinical evaluation of adoptive therapy strategies to eliminate the product-to-product variability of transgene expression otherwise intrinsic to transduction and other genetic modification procedures without subsequent selection. Immunotherapy using genetically redirected immune cells is an attractive approach for treating minimal residual disease in a variety of cancer patients. However, immunologic rejection of cell products expressing antibiotic selection proteins as part of the transduction strategy has impeded this strategy. A novel selection marker that is not expressed on human lymphocytes, does not contain endogenous signaling or trafficking function, and is recognized by a known, preferably commercially available, pharmaceutical grade

antibody reagent that can be utilized for selection, *in vivo* tracking, and depletion of transduced cells would be a significant improvement in the art.

Summary

[0004] Products and methods for purification, both *in vivo* and *ex vivo*, of genetically modified cells are provided herein. The genetically modified cells may be modified by transduction, or any other process that adds, deletes, alters, or disrupts an endogenous nucleotide sequence. The genetically modified cells may be transduced T cells with altered activity, including altered immunoactivity.

[0005] According to a first aspect of the present invention, there is provided a modified EGFR gene, comprising an EGFR Domain III and an EGFR Domain IV, but lacking an EGFR Domain I, EGFR Domain II, EGFR Juxtamembrane Domain, and an EGFR Tyrosine Kinase Domain.

[0005a] According to a second aspect of the present invention, there is provided a population of human T-cells transfected with a gene according to the first aspect of the invention.

[0005b] According to a third aspect of the present invention, there is provided an in vitro method of enriching or selecting the T-cells according to second aspect of the invention, comprising contacting the T-cells with an antibody that recognizes the truncated non-immunogenic endogenous cell surface molecule.

[0005c] According to a fourth aspect of the present invention, there is provided a method of depleting the T-cells according to second aspect of the invention in vivo, wherein said T cells are transfected with a genetically modified Epidermal Growth Factor Receptor (EGFR) gene that is coupled to a CD19CAR and a C-terminal 2A cleavable linker, wherein the T-cells encode an amino acid sequence comprising SEQ ID NO:6, comprising contacting the T-cells with an antibody that recognizes the truncated non-immunogenic endogenous cell surface molecule.

[0005d] Described herein is a non-immunogenic selection epitope compatible with immunomagnetic selection facilitates immunotherapy in cancer patients without undesirable immunologic rejection of cell products (i.e. as seen when expressing antibiotic selection proteins) may be generated by removing certain amino acid sequences of the protein. Also described herein is the non-immunogenic selection epitope is a gene encoding an endogenous

cell-surface molecule that is modified or truncated to retain an extracellular epitope recognized by a known antibody or functional fragment thereof, and to remove any signaling or trafficking domains and/or any extracellular domains unrecognized by the known antibody. The removal of the signaling or trafficking domains and/or any extracellular domains unrecognized by the known antibody renders the endogenous cell-surface molecule inert, which is a desired property for the molecule. The non-immunogenic selection epitope may also be used for as a selection tool or tracking marker.

[0006] The modified endogenous cell-surface molecule may be, but is not limited to, any cell-surface related receptor, ligand, glycoprotein, cell adhesion molecule, antigen, integrin or cluster of differentiation (CD) that is modified as

described herein. In some embodiments, the modified endogenous cell-surface molecule is a truncated tyrosine kinase receptor. In one aspect, the truncated tyrosine kinase receptor is a member of the epidermal growth factor receptor family (e.g., ErbB1, ErbB2, ErbB3, ErbB4).

[0007] Epidermal growth factor receptor, also known as EGFR, ErbB1 and HER1, is a cell-surface receptor for members of the epidermal growth factor family of extracellular ligands. Alterations in EGFR activity have been implicated in certain cancers. In a first aspect, a gene encoding an EGFR polypeptide comprising human epidermal growth factor receptor (EGFR) that is constructed by removal of nucleic acid sequences that encode polypeptides including the membrane distal EGF-binding domain and the cytoplasmic signaling tail (a "truncated EGFR" or "EGFRt"), but retains the extracellular membrane proximal epitope recognized by an anti-EGFR antibody. Preferably, the antibody is a known, commercially available anti-EGFR monoclonal antibody, such as cetuximab, matuzumab, necitumumab or panitumumab.

[0008] Application of biotinylated-cetuximab to immunomagnetic selection in combination with anti-biotin microbeads successfully enriches T cells that have been lentivirally transduced with EGFRt-containing constructs from as low as 2% of the population to greater than 90% purity without observable toxicity to the cell preparation. Constitutive expression of this inert EGFRt molecule does not affect T cell phenotype or effector function as directed by the coordinately expressed chimeric antigen receptor (CAR), CD19R. Through flow cytometric analysis, EGFRt was successfully utilized as an *in vivo* tracking marker for T cell engraftment in mice. Furthermore, EGFRt was demonstrated to have suicide gene potential through Erbitux® mediated antibody dependent cellular cytotoxicity (ADCC) pathways. Thus,

EGFRt may be used as a non-immunogenic selection tool, tracking marker, and suicide gene for transduced T cells that have immunotherapeutic potential. The EGFRt nucleic acid may also be detected by means well known in the art.

[0009] In another embodiment, methods of discovering and designing modified, truncated or altered endogenous cell-surface molecules which bind to antibodies, preferably commercially available antibodies, as described herein are provided. The methods include modeling the protein of interest and truncating functional portions, while leaving the antibody-binding portions intact. The resulting modified receptor or ligand can be sorted using a labeled antibody and then enriched such that the concentration of the modified receptor or ligand is increased.

[0010] Yet another embodiment provides a method of selecting transduced T cells comprising transducing T cells with a modified, truncated or altered endogenous cell-surface molecule gene sequence (e.g., truncated EGFR) and then applying an antibody that binds the modified ligand or receptor sequence to the transduced T cells. If the modified receptor sequence is EGFRt, the antibody is preferably a biotinylated anti-EGFR monoclonal antibody. The T cells are then sorted by adding anti-biotin microbeads and selecting the T cells using immunomagnetic separation, adding fluorochrome-conjugated anti-biotin and selecting the T cells using Fluorescence Activated Cell Sorting, or any other reliable method of sorting the cells. The modified ligand or receptor sequences, such as the EGFRt sequence, may be contained in a suitable transfer vehicle such as a lentiviral vector.

[0011] These and other embodiments are further explained in the drawing and detailed description herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] Figure 1 is a molecular model of EGFR vs. EGFRt proteins based on the crystal structure files. The EGFR structure on the left shows a full-length EGFR with the structure of the four extracellular domains (Domains I-IV). The middle structure shows the truncated EGFR (EGFRt), which is missing Domain I, Domain II, the Juxatmembrane Domain, and the Tyrosine Kinase Domain as compared to an unmodified EGFR. The EGFRt on the right shows truncated structure bound to Eribitux® Fab, comprised of V_H-C_{H1} and V_L-C_L. The domains are separated with dotted lines.

[0013] Figure 2 illustrates the selection of $EGFRt^+$ T cells using biotinylated cetuximab (referred to in the figure as Erbitux®). Figure 2a is a schematic of the cetuximab biotinylation and reformulation process. Figure 2b is a graph showing titration of biotinylated cetuximab. 10^6 $EGFR^+$ cells were stained with either 0μg (black), 1.45μg (red), 0.145μg (orange), 14.5ng (yellow), 1.45ng (green), 0.145ng (blue) or 14.5pg (purple) of biotinylated cetuximab followed by 0.5μg PE-conjugated streptavidin and analyzed by flow cytometry. 14.5ng or more of biotinylated cetuximab was deemed sufficient for future staining. Figure 2c depicts schematics of both the immunomagnetic (top) and the fluorescence activated cell sorting (bottom) EGFRt selection procedures.

[0014] Figure 2d shows immunomagnetic selection of various T cell lines lentivirally transduced with CAR and EGFRt containing constructs. Schematics of the CD19CAR-T2A-EGFRt (left) and CD19CAR-T2A-EGFRt-IMPDH2dm (right) constructs contained in lentiviral vectors are shown above the corresponding pre- and post-selection flow cytometric analyses for surface EGFRt expression. Codon optimized sequence portions of the CD19-specific, CD28 co-stimulatory CAR,

followed by the self-cleavable T2A, EGFRt and IMPDH2dm selection markers are indicated, along with the Elongation Factor 1 promoter sequences (EF-1p), and the GCSFR alpha chain signal sequences (GCSFRss, which directs surface expression). Flow cytometric analysis of lentivirally transduced T cell lines that had been stained with a biotinylated-cetuximab antibody and PE-conjugated anti-biotin antibody (black histograms) was performed on both the input T cells (PRE SLXN) and the positive fraction obtained from AutoMACS™ (POS FRXN). Open histograms represent staining with PE-conjugated anti-biotin antibody alone, and the percent positive cells are indicated in each histogram. Selection of $CD19CAR^+EGFRt^+$ Line A occurred 3 days after transduction of T cell blasts. Selection of $CD19CAR^+EGFRt^+$ Line B occurred after 3 REM stimulations of transduced CMVpp65-specific T_{CM}-derived cells. Selection of $CD19CAR^+EGFRt^+$ Line C occurred after 2 REM stimulations of transduced $CD8^+$ T_{CM}-derived cells. Selection of $CD19CAR^+EGFRt^+$ Line D occurred after 1 REM stimulation of transduced T_{EM} -derived cells. Selection of $CD19CAR^+EGFRt^+IMPDH2dm^+$ Line E occurred after 1 REM stimulation of transduced T_{CM}-derived cells.

[0015] Figure 3 shows that the EGFRt expressed on selected T cells is inert. In Figure 3a, EGFRt expressed on T cells is not phosphorylated upon co-incubation with EGF. Negative control T cells, $CD19CAR^+EGFRt^+$ Line A cells, or A431 cells were incubated for 5 minutes with or without either 100ng/mL EGF or cetuximab (referred to in the figure as Erbtx) and then lysed in the presence of phosphatase inhibitor. Lysates run on Western blots were then probed using antibodies specific for either β-actin, the cytoplasmic domain of EGFR, or the phosphorylated tyrosine at position 1068 of EGFR. Figure 3b shows that EGF does not bind to the surface of EGFRt expressing T cells. A431, Line A, and negative control T cells were stained

with PE-conjugated anti-EGFR, or either biotinylated cetuximab or biotinylated EGF followed by PE-conjugated streptavidin (black histogram) versus PE-conjugated isotype control Ab or streptavidin alone (open histogram) by flow cytometry. Percent positive staining is indicated in each histogram.

[0016] Figure 4 illustrates that selected EGFRt$^+$ CD19R$^+$ T cells can be expanded with maintenance of effector phenotype. Figure 4a is a line graph showing expansion of EGFRt-selected T cells, Lines A-E, over 12 or more days after rapid expansion medium (REM) stimulation was initiated on the day of AutoMACS™ selection (day 0). (MACS is magnetic activated cell sorting.) Expansion of T cells in rapid expansion medium (REM) involved the incubation of 10^6 T cells with 30 ng/mL anti-CD3ε (OKT3; Ortho Biotech, Raritan, NJ), 5 x 10^7 γ-irradiated PBMCs (3500 cGy), and 10^7 γ-irradiated LCLs (8000 cGy) in 50 mL CM; with addition of 50U/mL rhIL-2 and 10ng/ml rhIL-15 (CellGenix) every 48 hours, beginning on day 1. T cells were re-stimulated in this manner every 14 days. Figure 4b shows histograms representing EGFRt-selected T cells (11 to 13 days after stimulation) that were phenotyped for surface EGFR (i.e., EGFRt, with biotinylated cetuximab), Fc (i.e., CAR), and T cell markers CD4 or CD8, (black histogram) vs. isotype control Ab (open histogram) by flow cytometry. Percent positive staining is indicated in each histogram. "N.D." indicates no data. Figure 4C are five lines graphs, one for each of Lines A-E, of EGFRt-selected T cells (within 11 to 15 days after REM stimulation) incubated for 4 hours with ^{51}Cr-labled NS0, U251T, CD19t-expressing NS0, CMV pp65-expressing U251T, CD19-expressing Daudi or SupB15, or OKT3-expressing LCL cells as targets at the indicated E:T ratios. Chromium release was measured to determine cytotoxic activity. Figure 4d is a graph showing MPA resistance of the CD19CAR$^+$EGFRt$^+$IMPDH2dm$^+$ Line E. Control T cells that do not express

IMPDH2dm and EGFRt-selected IMPDH2dm-expressing Line E cells were cultured either with or without 1μM MPA and total cell numbers were monitored.

[0017] Figure 5 shows EGFRt expression can be used as a tracking marker for in vivo T cell engraftment. Day 36 bone marrow harvested from a control mouse or from a mouse that had received 10^7 CD19CAR$^+$EGFRt$^+$ Line C at day 0 was stained using PerCP-conjugated anti-human CD45 and biotinylated cetuximab ("Bio-Erb") followed by PE-conjugated streptavidin. Quadrants were created based on isotype control staining, and percent positive staining in each quadrant is indicated in each histogram.

[0018] Figure 6 is a graph showing EGFRt expression targets T cells for cetuximab (referred to in the figure as Erbitux®) mediated ADCC. ^{51}Cr-labeled Line A cells were pre-incubated either with or without up to 20μg/mL of cetuximab or the CD20-specific mAb Rituxan as a negative control prior to addition of human PBMC as effectors.

[0019] Figure 7 is the nucleotide (sense strand is SEQ ID NO: 1, antisense strand is SEQ ID NO: 2) and amino acid (SEQ ID NO: 3) sequences of GMCSFR alpha chain signal sequence linked to EGFRt. The GMCSFR alpha chain signal sequence, which directs surface expression, is encoded by nucleotides 1-66. EGFRt is encoded by nucleotides 67-1071.

[0020] Figure 8 is the nucleotide (sense strand is SEQ ID NO: 4, antisense strand is SEQ ID NO: 5) and amino acid (SEQ ID NO: 6) sequences of CD19R-CD28gg-Zeta(CO)-T2A-EGFRt. CD19R-CD28gg-Zeta(CO) is encoded by nucleotides 1-2040; T2A is encoded by nucleotides 2041-2112; GMCSFR is encoded by nucleotides 2113-2178; EGFRt is encoded by nucleotides 2179-3186.

[0021] Figure 9 is a graph showing CD19R-CD28gg-Zeta(CO)-T2A-EGFRt expression. Transduction of anti-CD3/anti-CD28 bead stimulated primary T cell blasts with the CD19R-CD28gg-Zeta(CO)-T2A-EGFRt_epHIV7 lentiviral vector (MOI = 3) results in surface detection of both the CAR (using a biotinylated anti-Fc Ab and streptavidin-PE) and the truncated EGFR molecule (using a biotinylated cetuximab Ab and streptavidin-PE) by flow cytometry on day 4. The white peak in each panel is non-transduced control T cell blasts.

[0022] Figure 10 is a schema showing a possible process flow for clinical trials for testing products of the present disclosure.

DETAILED DESCRIPTION

[0023] Certain embodiments of the invention are described in detail, using specific examples, sequences, and drawings. The enumerated embodiments are not intended to limit the invention to those embodiments, as the invention is intended to cover all alternatives, modifications, and equivalents, which may be included within the scope of the present invention as defined by the claims. One skilled in the art will recognize many methods and materials similar or equivalent to those described herein, which could be used in the practice of the present invention.

[0024] Erbitux® is a registered trademark for the anti-EGFR monoclonal antibody cetuximab and is intended to independently include the trade name product formulation, the generic drug, and the active pharmaceutical ingredient(s) of the trade name product.

[0025] The term "genetic modification" means any process that adds, deletes, alters, or disrupts an endogenous nucleotide sequence and includes, but is not limited to viral mediated gene transfer, liposome mediated transfer, transformation, transfection and transduction, e.g., viral mediated gene transfer such as the use of

vectors based on DNA viruses such as lentivirus, adenovirus, retroviruses, adeno-associated virus and herpes virus.

[0026] The term "antibody" includes monoclonal antibodies, polyclonal antibodies, dimers, multimers, multispecific antibodies and antibody fragments that may be human, mouse, humanized, chimeric, or derived from another species. A "monoclonal antibody" is an antibody obtained from a population of substantially homogeneous antibodies that is being directed against a specific antigenic site.

[0027] "Variant" refers to polypeptides having amino acid sequences that differ to some extent from a native sequence polypeptide. Ordinarily, amino acid sequence variants will possess at least about 80% sequence identity, more preferably, at least about 90% homologous by sequence. The amino acid sequence variants may possess substitutions, deletions, and/or insertions at certain positions within the reference amino acid sequence.

[0028] "Percentage identity" or "percent identity" is defined as the percentage of residues in the amino acid sequence variant that are identical after best aligning the sequences and introducing gaps, if necessary, to achieve the maximum percent sequence identity. Methods and computer programs for the alignment are well known in the art. Such programs include GAP, BESTFIT, FASTA, BLAST or Align 2.

[0029] "Antibody-dependent cell-mediated cytotoxicity" and "ADCC" refer to a cell-mediated reaction in which nonspecific cytotoxic cells that express Fc receptors, such as natural killer cells, neutrophils, and macrophages, recognize bound antibody on a target cell and cause lysis of the target cell. ADCC activity may be assessed using methods, such as those described in U.S. Pat. No. 5,821,337.

[0030] "Effector cells" are leukocytes which express one or more constant region receptors and perform effector functions.

[0031] To “treat" a disease or a disorder, such as cancer, means to take either therapeutic measures or preventative measures to lessen or abate the disease or disorder. Such treatment includes prevention, alleviation of symptoms, diminishment or stabilization of scope, and/or remission.

[0032] The term "therapeutically effective amount" refers to an amount of a compound or molecule effective to treat a disease or disorder.

[0033] “Cancer" refers to cells undergoing uncontrolled cellular growth. Examples of cancer include colorectal cancer and head and neck cancer. A "chemotherapeutic agent" is a chemical compound useful in the treatment of cancer.

[0034] A “cytokine" is a protein released by one cell to act on another cell as an intercellular mediator.

[0035] “Non-immunogenic” refers to a material that does not initiate, provoke or enhance an immune response where the immune response includes the adaptive and/or innate immune responses.

[0036] The term "gene" means the segment of DNA involved in producing a polypeptide chain; it includes regions preceding and following the coding region "leader and trailer" as well as intervening sequences (introns) between individual coding segments (exons). Some genes may be developed which lack, in whole or in part, introns. Some leader sequences may enhance translation of the nucleic acid into polypeptides.

[0037] The term "isolated" means that the material is removed from its original environment (e.g., the natural environment if it is naturally occurring). For example, a naturally-occurring polynucleotide or polypeptide present in a living animal is not isolated, but the same polynucleotide or polypeptide, separated from some or all of the coexisting materials in the natural system, is isolated. Such polynucleotides

could be part of a vector and/or such polynucleotides or polypeptides could be part of a composition, and still be isolated in that such vector or composition is not part of its natural environment.

[0038] As used herein, a "vector" may be any agent capable of delivering or maintaining nucleic acid in a host cell, and includes viral vectors (e.g. retroviral vectors, lentiviral vectors, adenoviral vectors, or adeno-associated viral vectors), plasmids, naked nucleic acids, nucleic acids complexed with polypeptide or other molecules and nucleic acids immobilized onto solid phase particles. The appropriate DNA sequence may be inserted into the vector by a variety of procedures. In general, the DNA sequence is inserted into an appropriate restriction endonuclease site(s) by procedures known in the art. Such procedures and others are deemed to be within the scope of those skilled in the art. Transcription of the DNA encoding the polypeptides of the present invention by higher eukaryotes is increased by inserting an enhancer sequence into the vector. Enhancers are cis-acting elements of DNA, usually about from 10 to 300 bp that act on a promoter to increase its transcription. Examples including the SV40 enhancer on the late side of the replication origin bp 100 to 270, a cytomegalovirus early promoter enhancer, the polyoma enhancer on the late side of the replication origin, and adenovirus enhancers.

[0039] "Receptor" means a polypeptide that is capable of specific binding to a molecule. Whereas many receptors may typically operate on the surface of a cell, some receptors may bind ligands when located inside the cell (and prior to transport to the surface) or may reside predominantly intra-cellularly and bind ligand therein.

[0040] "Antibody or functional fragment thereof" means an immunoglobulin molecule that specifically binds to, or is immunologically reactive with a particular antigen or epitope, and includes both polyclonal and monoclonal antibodies. The

term antibody includes genetically engineered or otherwise modified forms of immunoglobulins, such as intrabodies, peptibodies, chimeric antibodies, fully human antibodies, humanized antibodies, and heteroconjugate antibodies (e.g., bispecific antibodies, diabodies, triabodies, and tetrabodies). The term functional antibody fragment includes antigen binding fragments of antibodies, including e.g., Fab', F(ab').sub.2, Fab, Fv, rIgG, and scFv fragments. The term scFv refers to a single chain Fv antibody in which the variable domains of the heavy chain and of the light chain of a traditional two chain antibody have been joined to form one chain.

[0041] In one embodiment, a gene encoding a modified endogenous cell-surface molecule that may be used as a non-immunogenic selection epitope compatible with immunomagnetic selection is provided. Such a non-immunogenic selection epitope may facilitate immunotherapy in cancer patients without undesirable immunologic rejection of cell products. The endogenous cell surface molecule may be modified or truncated to retain an extracellular epitope recognized by a known antibody or functional fragment thereof, and to remove any signaling or trafficking domains and/or any extracellular domains unrecognized by said known antibody. A modified endogenous cell surface molecule which lacks a signaling or trafficking domain and/or any extracellular domains unrecognized by said known antibody is rendered inert.

[0042] The modified endogenous cell-surface molecule may be, but is not limited to, any non-immunogenic cell-surface related receptor, glycoprotein, cell adhesion molecule, antigen, integrin or cluster of differentiation (CD) that is modified as described herein. Modification of such cell-surface molecules is accomplished by keeping an epitope that is recognized by a known antibody or functional fragment thereof; and removing any signaling or trafficking domains and/or any extracellular

domains unrecognized by a known antibody. Removal of the signaling or trafficking domains and/or any extracellular domains unrecognized by a known antibody renders the endogenous cell-surface molecule non-immunogenic and/or inert.

[0043] Examples of endogenous cell-surface molecules that may be modified or truncated according to the embodiments described herein include, but are not limited to EpCAM, VEGFR, integrins (e.g., integrins αvβ3, α4, αIIbβ3, α4β7, α5β1, αvβ3, αv), TNF receptor superfamily (e.g., TRAIL-R1, TRAIL-R2), PDGF Receptor, interferon receptor, folate receptor, GPNMB, ICAM-1, HLA-DR, CEA, CA-125, MUC1, TAG-72, IL-6 receptor, 5T4, GD2, GD3, or clusters of differentiation (e.g., CD2, CD3, CD4, CD5, CD11, CD11a/LFA-1, CD15, CD18/ITGB2, CD19, CD20, CD22, CD23/IgE Receptor, CD25, CD28, CD30, CD33, CD38, CD40, CD41, CD44, CD51, CD52, CD62L, CD74, CD80, CD125, CD147/basigin, CD152/CTLA-4, CD154/CD40L, CD195/CCR5, CD319/SLAMF7).

[0044] Corresponding commercial antibodies that may be used to recognize a modified or truncated endogenous cell-surface molecule include, but are not limited to, 3F8, abagovomab, abciximab, adecatumumab, afutuzumab, alemtuzumab, altumomab pentetate, anatumomab mafenatox, apolizumab, arcitumomab, aselizumab, atlizumab (= tocilizumab), basiliximab, bectumomab, benralizumab, besilesomab, bivatuzumab mertansine, blinatumomab, brentuximab vedotin, cantuzumab mertansine, capromab pendetide, catumaxomab, CC49, cedelizumab, celmoleukin, citatuzumab bogatox, clenoliximab, clivatuzumab tetraxetan, CNTO-95, conatumumab, dacetuzumab, daclizumab, daratumumab, detumomab, ecromeximab, edrecolomab, efalizumab, elotuzumab, enlimomab pegol, epitumomab cituxetan, epratuzumab, erlizumab, etaracizumab, fanolesomab, faralimomab, farletuzumab, galiximab, gavilimomab, gemtuzumab ozogamicin,

glembatumumab vedotin, gomiliximab, ibalizumab, ibritumomab tiuxetan, igovomab, intetumumab, iratumumab, inolimomab, inotuzumab ozogamicin, ipilimumab, keliximab, labetuzumab, lintuzumab, lexatumumab, lucatumumab, lumiliximab, mapatumumab, maslimomab, milatuzumab, minretumomab, mitumomab, muromonab-CD3, naptumomab estafenatox, natalizumab, ocrelizumab, odulimomab, ofatumumab, olaratumab, oportuzumab monatox, oregovomab, otelixizumab, pemtumomab, priliximab, PRO 140, rituximab, rovelizumab, ruplizumab, satumomab pendetide, siplizumab, sontuzumab, tadocizumab, taplitumomab paptox, teneliximab, teplizumab, TGN1412, ticilimumab (= tremelimumab), tigatuzumab, tocilizumab (= atlizumab), toralizumab, tositumomab, tremelimumab, tucotuzumab, vedolizumab, veltuzumab, visilizumab, vitaxin, volociximab, votumumab, zanolimumab, ziralimumab, zolimomab aritox.

[0045] In some embodiments, the modified endogenous cell-surface molecule is encoded by a modified or truncated tyrosine kinase receptor gene. Examples of tyrosine kinase receptors that may be modified or truncated according to the embodiments described herein include, but are not limited to, members of the endothelial growth factor receptor family (EGRF/ErbB1/HER1; ErbB2/HER2/neu; ErbB3/HER3; ErbB4/HER4), hepatocyte growth factor receptor (HGFR/c-MET) and insulin-like growth factor receptor-1 (IGF-1R). According to some embodiments, modified tyrosine kinase receptors retain an extracellular epitope recognized by a known antibody or functional fragment thereof, and lack at least a tyrosine kinase domain. A modified tyrosine kinase receptor which lacks at least a tyrosine kinase domain renders the receptor inert.

[0046] Commercial antibodies that may be used to recognize a modified tyrosine kinase receptor include, but are not limited to AMG-102, AMG-479,

BIIB022OA-5D5, CP-751,871, IMC-A12, R1507, cetuximab, cixutumumab, ertumaxomab, figitumumab, matuzumab, necitumumab, panitumumab, pertuzumab, nimotuzumab, robatumumab, trastuzumab, zalutumumab.

[0047] In one embodiment, the modified endogenous cell surface molecule is a truncated EGFR (tEGFR) that lacks the membrane distal EGF-binding domain and the cytoplasmic signaling tail, but retains the extracellular membrane proximal epitope recognized by a known antibody or functional fragment thereof (e.g., cetuximab, matuzumab, necitumumab or panitumumab). In another embodiment, the tEGFR is missing Domain I, Domain II, the Juxtamembrane Domain and the Tyrosine Kinase Domain as compared to an unmodified EGFR (Figure 1).

[0048] A gene encoding a modified endogenous cell surface molecule may be used as a cell selection or enrichment marker for a genetically modified population of immune cells (e.g., T cells). The gene encoding a modified endogenous cell surface molecule may be coupled to a gene encoding a tumor targeting chimeric antigen receptor (CAR). These genes may be inserted into a vector to transduce the population of T cells to be genetically modified. After transduction, the cells that are successfully transduced and express the CAR and modified endogenous cell-surface molecule are enriched by any suitable purification method, such as immunomagnetic purification with anti-biotin microbeads or fluorochrome-conjugated anti-biotin for fluorescence activated cell sorting, using a commercial antibody that recognizes the modified endogenous cell-surface molecule expressed by the transduced cell.

[0049] In another embodiment, a gene encoding a truncated human epidermal growth factor receptor (EGFRt) that lacks the membrane distal EGF-binding domain and the cytoplasmic signaling tail, but retains the extracellular membrane proximal epitope recognized by the FDA-approved anti-EGFR monoclonal antibody (mAb)

cetuximab or another anti-EGFR antibody, is constructed and described herein. The EGFRt may be coupled with chimeric antigen receptors specific for a tumor associated antigen. The tumor associated antigen may be CD19, CD20, or CD22, or any other tumor associated antigen, but is preferably CD19 (CD19CAR). The tumor associated antigen is followed by a C-terminal 2A cleavable linker and the coding sequence for EGFRt. The biotinylated-cetuximab may be used in conjunction with commercially available anti-biotin microbeads for the purpose of immunomagnetic purification of the tumor associated antigen/CAR-expressing transductants. In the instance where the tumor associated antigen is CD19 the product is CD19CAR-expressing transductants. Alternatively, the biotinylated-cetuximab may be used in conjunction with Fluorochrome-conjugated anti-biotin for fluorescence activated cell sorting.

[0050] In another embodiment, a modified endogenous cell-surface molecule may be used as a marker for *in vivo* T cell engraftment. For example, when the modified endogenous cell-surface molecule is EGFRt, the EGFRt may be used to track the uptake of the T cells to which it is attached *in vivo* without affecting cellular function of the T cells or the cells to which the T cells are targeted, such as bone marrow cells in a transplant situation. The use of cetuximab conjugated to probes or reporter genes such as sr39TK may be used to improve the tracking potential of EGFRt-expressing cells to patients via PET imaging techniques.

[0051] In a separate embodiment, a modified endogenous cell-surface molecule may be used to induce cell suicide. For example, EGFRt may be used as a suicide gene via cetuximab mediated complement and/or antibody dependent cell mediated cytotoxicity (ADCC) pathways. The fact that cetuximab is a therapeutic

FDA-approved antibody further facilitates the suicide gene potential of EGFRt in the clinical setting.

[0052] In other embodiments, the truncated epidermal growth factor receptor (EGFRt) selection epitope or other modified cell-surface molecule is attached to other sequences. One exemplar sequence is the GMCSFR alpha chain signal sequence, which directs surface expression, attached to EGFRt. GMCSFR is encoded by nucleotides 1-66 and EGFRt is encoded by nucleotides 67-1071 of SEQ ID NO: 1. See Figure 7. Also in Figure 7 is the antisense strand (SEQ ID NO: 2) and amino acid (SEQ ID NO: 3) sequences of GMCSFR alpha chain signal sequence linked to EGFRt. Another such sequence is a codon-optimized cDNA sequence encoding an anti-CD19 costimulatory chimeric antigen receptor (CD19R-CD28gg-Zeta(CO)), and a cleavable T2A linker. Cytotoxic T lymphocytes (CTLs) modified to express a CD19-specific chimeric antigen receptor (CAR) that signals via a cytoplasmic costimulatory (CD28) domain fused to the cytoplasmic CD3-ζ domain exhibits superior anti-tumor potency that can be attributed to CD28-mediated survival and enhanced cytokine production. This construct may be further modified to incorporate a C-terminal 2A cleavable linker followed by the coding sequence for a truncated human EGFR (EGFRt) for the purpose of immunomagnetic purification of CAR-expressing transductants using cetuximab-biotin/anti-biotin microbeads. See the CD19R-CD28gg-Zeta(CO)-T2A-EGFRt sequence attached as Figure 8, SEQ ID NOS: 4 (nucleotide sense strand), 5 (nucleotide anti-sense strand), and 6 (protein). Lentivector transduction of primary human T cells with this codon-optimized cDNA directs the coordinated expression of the CAR and EGFRt (Fig. 9).

[0053] To eliminate variability between transgene expression products otherwise intrinsic to transduction procedures without subsequent selection, a non-

immunogenic selection epitope, EGFRt, compatible with immunomagnetic selection using the CliniMACS device (Miltenyi Biotec, Bergisch Gladbach, Germany) was developed. For example, EGFRt is a truncated human epidermal growth factor receptor that lacks the membrane distal EGF-binding domain and the ectoplasmic signaling tail, but retains the extracellular membrane proximal epitope recognized by the commercial anti-EGFR mAb cetuximab. See Figure 1. Biotinylated-cetuximab is applied to immunomagnetic selection in combination with anti-biotin microbeads (Miltenyi). Human OKT3 blasts that had been lentivirally transduced with CD19R-CD28gg-Zeta(CO)-T2A-EGFRt were subjected to immunomagnetic selection using the Miltenyi AutoMACS device, and the frequency of EGFRt+CAR+ T cells was enriched from 22% (pre-selection) to 99% (post-selection) without observable toxicity to the cell preparation (Fig. 3). It is also possible that, instead of or in addition to immunomagnetic sorting, the EGFRt can be purified using fluorescence-based cell sorting techniques.

[0054] Due to the absence of the EGF-binding domains and intracellular signaling domains, EGFRt is inactive when expressed by T cells. Importantly, the EGFRt-selected T cells maintain their desired effector phenotype – including anti-tumor cyotoxic activity mediated by the chimeric antigen receptor that is coordinately expressed with the EGFRt - and remain amenable to established expansion protocols.

[0055] Overall, this EGFRt has various advantages for immunotherapeutic cell products compared to other selection markers that have been previously reported. Specifically, unlike truncated CD4 and CD19, it is not endogenously expressed by subpopulations of lymphocytes. Furthermore, in contrast to truncated CD34 and low affinity nerve growth factor receptor, it does not have any activity that might

negatively affect the immune cell product (i.e., in terms of signaling or trafficking). Lastly, it alone can be bound/recognized by a known, preferably commercially available, pharmaceutical grade antibody reagent, i.e., cetuximab. Together, these attributes make EGFRt a superior selection marker for any transfection/transduction system that can be applied to the generation of cell products for adoptive immunotherapy. Thus, EGFRt is well suited to be used as a selection marker for lentivirally transduced T cells of immunotherapeutic relevance.

[0056] Also provided are methods for identifying new therapeutic cell products having the following criteria: a modified endogenous cell-surface molecule, ligand or receptor that is not, as modified, endogenously expressed in the subject in which it is intended to be therapeutically utilized, does not have any immunoactivity or other functional activity that would hinder the functioning of the product or the subject into which the product is administered, and that it can be recognized by a known antibody.

[0057] Having described the invention with reference to the embodiments and illustrative examples, those in the art may appreciate modifications to the invention as described and illustrated that do not depart from the spirit and scope of the invention as disclosed in the specification. The examples are set forth to aid in understanding the invention but are not intended to, and should not be construed to limit its scope in any way. The examples do not include detailed descriptions of conventional methods. Such methods are well known to those of ordinary skill in the art and are described in numerous publications.

Example 1: Generation of EGFRt and Immunomagnetic selection of EGFRt expressing T cells

Materials & Methods

Antibodies and Flow Cytometry

[0058] FITC-, PE- and PerCP-conjugated isotype controls, PerCP-conjugated anti-CD8, FITC conjugated anti-CD4, PE-conjugated anti-IFNγ, PerCP-conjugated anti-CD45 and PE-conjugated streptavidin were obtained from BD Biosciences (San Jose, CA). Biotinylated anti-Fc was purchased from Jackson ImmunoResearch Laboratories, Inc. (Westgrove, PA). PE-conjugated anti-Biotin was purchased from Miltenyi Biotec (Auburn, CA). Biotinylated EGF was purchased from Molecular Probes® Invitrogen (Carlsbad, CA). PE-conjugated anti-EGFR was purchased from Abcam Inc. (Cambridge, MA). All antibodies and biotin-EGF were used according to the manufacturer's instructions. Flow cytometric data acquisition was performed on a FACScalibur (BD Biosciences), and the percentage of cells in a region of analysis was calculated using FCS Express V3 (De Novo Software, Los Angeles, CA).

[0059] For generation of the biotinylated-cetuximab, 200mg of cetuximab (Erbitux®) was buffer exchanged (19 hours) to PBS (D-PBS, pH 7.5± 0.1) using a MidGee Hoop Cartridge (UFP-30-E-H42LA) with 527mL. The material at 2mg/mL was then modified at a 20:1 ratio using Sulfo-NHS-LC-Biotin in a reaction that was carried out for 1 hour at room temperature and then diafiltered to remove the excess biotin. The 200 mg of biotinylated cetuximab was then buffer exchanged (18 hours) to PBS (D-PBS, pH 7.5± 0.1) using MidGee Hoop Cartridge (UFP-30-E-H42LA) with 533 mL. Glycerol was added to a final concentration of 20% and then the material was frozen in vials.

Cell lines

[0060] Unless otherwise indicated, all cell lines were maintained in RPMI 1640 (Irvine Scientific, Santa Ana, CA) supplemented with 2 mM L-glutamine (Irvine Scientific), 25 mM *N*-2-hydroxyethylpiperazine-*N'*-2-ethanesulfonic acid (HEPES, Irvine Scientific), 100 U/mL penicillin, 0.1 mg/mL streptomycin (Irvine Scientific), and 10% heat-inactivated fetal calf serum (FCS, Hyclone, Logan, UT), hereafter referred to as culture media (CM).

[0061] To generate T cells, human peripheral blood mononuclear cells (PBMC) were isolated by density gradient centrifugation over Ficoll-Paque (Pharmacia Biotech, Piscataway, NJ) from heparinized peripheral blood obtained from consented healthy donors participating on a City of Hope National Medical Center Internal Review Board-approved protocol. For generation of Line A, washed PBMC were stimulated with 25U/mL IL-2 and a 1:1 (cell:bead) ratio of Dynabeads® Human T expander CD3/CD28 (Invitrogen, Carlsbad, CA). For generation of the other lines, washed PBMC were first autoMACS™ depleted using anti-CD45RA beads (Miltenyi Biotec) per the manufacturer's protocol, and in some cases also depleted with PE-conjugated anti-CD4 (BD Biosciences) with anti-PE beads (Miltenyi Biotec). The resulting cells then underwent autoMACS™ positive selection using biotinylated DREG56 (anti-CD62L) and anti-biotin beads (Miltenyi Biotec) to produce purified $CD62L^{+}CD45RO^{+}$ T_{CM}. $CD8^{+}$ cells were further selected in some cases using AutoMACS™ (Miltenyi Biotec) per the manufacturer's protocol. CMV-specific cells were generated by stimulating T cells with 5U/ml rhIL-2 (Chiron, Emeryville, CA) and autologous irradiated viral antigen presenting cells at a 4:1 (responder:stimulator) ratio once a week for three weeks, using 10% human serum instead of FCS to avoid non-specific stimulation. The viral antigen presenting cells

were derived from PBMC that had been genetically modified to express CMVpp65 antigen.

[0062] PBMC were resuspended in nucleofection solution using the Human T cell Nucleofector kit (Amaxa Inc., Gaithersberg, MD), and 5 x 10^7 cells were aliquoted into 0.2-cm cuvettes containing 10μg HygroR-pp65_pEK (or pmaxGFP from Amaxa Inc., as a transfection control) in a final volume of 100 μL/cuvette, and electroporated using the Amaxa Nucleofector I (Amaxa Inc.), program U-14, after which cells were allowed to recover for 6 hours at 37°C prior to γ-irradiation (1200 cGy).

[0063] The CD19CAR-T2A-EGFRt_epHIV7 (pJ02104) and CD19CAR-T2A-EGFRt-T2A-IMPDH2dm_epHIV7 (pJ02111) lentiviral constructs contain a) the chimeric antigen receptor (CAR) sequences consisting of the V_H and V_L gene segments of the CD19-specific FmC63 mAb, an IgG1 hinge-C_{H2}-C_{H3}, the transmembrane and cytoplasmic signaling domains of the costimulatory molecule CD28, and the cytoplasmic domain of the CD3ζ chain[10]; b) the self-cleaving T2A sequence[11]; c) the truncated EGFR sequence (See Fig. 1); and d) the IMPDH2 double mutant that confers MPA-resistance, as indicated. Lentiviral transduction was carried out on T cells that were stimulated with either 30 ng/mL anti-CD3ε (OKT3; Ortho Biotech, Raritan, NJ) (i.e., for Line A) or human CD3/CD28Dynal beads at a 1:10 ratio (i.e., for Lines B, C, D and E) and 25U IL2/ml. Cells were cultured for up to 2 hours at 37°C on RetroNectin® (50ug/ml) coated plates prior to addition of the lentivirus at an MOI of 3 and 5μg/ml polyybrene. After 4 hours, warm medium was added to triple to volume, and the cells were then washed and plated in fresh media after 48hours. AutoMACS™ sorting of EGFRt-expressing cells was carried out with biotinylated cetuximab and anti-biotin microbeads (Miltenyi Biotec)

as per the manufacturer's instructions. Expansion of T cells in rapid expansion medium (REM) involved the incubation of 10^6 T cells with 30 ng/mL anti-CD3ε (OKT3; Ortho Biotech, Raritan, NJ), 5 x 10^7 γ-irradiated PBMCs (3500 cGy), and 10^7 γ-irradiated LCLs (8000 cGy) in 50 mL CM; with addition of 50U/mL rhIL-2 and 10ng/ml rhIL-15 (CellGenix) every 48 hours, beginning on day 1. T cells were re-stimulated in this manner every 14 days.

[0064] EBV-transformed lymphoblastoid cell lines (LCLs) were made from PBMC as previously described [13]. LCL-OKT3 cells were generated by resuspending LCL in nucleofection solution using the Amaxa Nucleofector kit T, adding OKT3-2A-Hygromycin_pEK (pJ01609) plasmid at 5μg/10^7 cells, and electroporating cells using the Amaxa Nucleofector I, program T-20. The resulting LCL - OKT3-2A-Hygro_pEK (cJ03987) were grown in CM containing 0.4mg/ml hygromycin. The mouse myeloma line NS0 (gift from Andrew Raubitschek, City of Hope National Medical Center, Duarte, CA) was resuspended in nucleofection solution using the Nucleofector kit T (Amaxa Inc., Gaithersberg, MD), CD19t-DHFRdm-2A-IL12_pEK (pJ01607) or GFP-IMPDH2dm-2A-IL15_pcDNA3.1(+) (pJ01043) plasmid was added at 5μg/5x10^6 cells, and cells were electroporated using the Amaxa Nucleofector I, program T-27. The resulting NS0 - CD19t-DHFRdm-2A-IL12_pEK (cJ03935) and NS0 - GFP:IMPDH2-IL15(IL2ss)_pcDNA3.1(+) (cJ02096) were grown in DMEM (Irvine Scientific, Santa Ana, CA) supplemented with 10% heat-inactivated FCS, 25mM HEPES, and 2 mM L-glutamine in the presence of either 0.05uM methotrexate (MTX) or 6 μM mycophenolic acid (MPA). The tumorigenic strain of U251, termed U251T, was a kind gift of Dr. Waldemar Debinski (Wake Forest, NC). U251T-pp65 were generated by lentiviral transduction of U251T with pp65-2A-eGFP-ffluc_epHIV7 (pJ01928) at an

MOI of 1. The resulting U251T - pp65-2A-eGFP-ffluc_epHIV7 were then FACS sorted for the GFP^+ population (cJ05058). The Daudi lymphoma line was purchased from ATCC and grown in media consisting of RPMI 1640 (Irvine Scientific), 2 mM L-Glutamine (Irvine Scientific), 10% heat-inactivated FCS (Hyclone). SupB15 acute lymphoblastic leukemia cells and A431 epidermoid carcinoma cells were purchased from ATCC.

Protein analysis

[0065] Cells (up to 10^7) were lysed with 80μL of 1% Triton-X lysis buffer containing phosphatase inhibitor cocktail II (Sigma-Aldrich Corp., St. Louis, MO) (1:20 of inhibitor to buffer by volume). 50μg of protein was loaded in each lane, and Western blots were probed with antibodies from the Phospho-EGF receptor antibody sampler kit (Cell Signaling Technology, Inc., Danvers, MA) followed by IRDye™ 680CW or 800CW conjugated goat anti-rabbit antibodies (LI-COR, Lincoln, NE), as well as the IRDye™ 800 conjugated anti-beta-Actin antibody (LI-COR) as per the manufacturers' instructions. Blots were imaged on the Odyssey Infrared Imaging System (LI-COR).

Chromium-release assays

[0066] The cytolytic activity of T cells was determined by 4-hour chromium-release assay (CRA), where effector cells were seeded into triplicate wells of V-bottom 96-well micro-plates containing $5x10^3$ ^{51}Cr-labeled targeT cells ($Na_2{}^{51}CrO_4$; (5mCi/mL); Amersham Pharmacia, Piscataway, NJ) at various E:T ratios in 200 uL of CM and incubated for 4 hours at 5% CO_2, 37°C. Plates were centrifuged, and 100 μl of supernatant was removed from each well to assess chromium release using a γ-counter (Packard Cobra II, Downer's Grove, IL). The percent specific lysis was calculated as follows: 100 x (experimental release – spontaneous release)/(maximum release – spontaneous release). Maximum release was

determined by measuring the ^{51}Cr content of wells containing labeled targets lysed with 2% SDS.

[0067] Antibody dependent cell mediated cytotoxicity was determined by chromium release as above using $5x10^3$ ^{51}Cr-labeled targeT cells that had been pre-incubated for 90 min with up to 10μg/mL of either cetuximab or rituximab (a CD20-specific mAb), washed and then co-incubated with $5x10^5$ freshly isolated PBMC.

T cell engraftment and cetuximab mediated suicide in vivo

[0068] For T cell engraftment, six- to ten-week old NOD/*Scid* IL-2RγC ^{null} mice are injected i.v. on day 0 with 10^7 T cells (Line C). $2x10^7$ irradiated (8000 rads) NS0 - GFP:IMPDH2-IL15(IL2ss)_pcDNA3.1(+) (cJ02096) cells are administered i.p. 3 times a week starting on day 0 to provide a systemic supply of human IL-15 *in vivo*. Bone marrow was harvested from euthanized animals and analyzed by flow cytometry. Antibody dependent cell mediated cytotoxicity assays are performed to determine the activity of cetuximab against $EGFRt^+$ T cells.

Results

Immunomagnetic selection of EGFRt expressing T cells

[0069] A truncated human EGFR (EGFRt), which contains only the transmembrane domain and extracellular domains III and IV of the full length EGFR, was generated as a non-immunogenic selection epitope compatible with immunomagnetic selection. As shown in the Figure 1 molecular model, the EGFRt retains the ability to be bound by cetuximab, but not have any signaling capacity due to the absence of the intracellular domains. Furthermore, it lacks the N-terminal domain required for EGF-binding.

[0070] To immunomagnetically select for EGFRt-expressing cells, biotinylated-cetuximab was generated (Fig. 2a, b) to be used in conjunction with

commercially available anti-biotin microbeads and an AutoMACS™ separator (Miltenyi Biotec) (Fig. 2c). Lentiviral transduction of various T cell lines with EGFRt-containing constructs, where the EGFRt gene was separated from other genes of interest on either one or both ends with the self-cleaving T2A sequence, consistently resulted in surface detection of the EGFRt molecule on less than 40% of the cells (Fig. 2d). Surface detection may also be accomplished with a EGFRt-sr39TK fusion. Immunomagnetic selection allowed for recovery of $EGFRt^+$ T cell populations with greater than 90% purity. T cell populations that underwent this transduction and selection procedure included anti-CD3/anti-CD28 bead stimulated T cell blasts (for Line A), central memory ($CD45RO^+CD62L^+$ T_{CM}) derived T cells (for Lines B, C and E), which in some cases were also pre-selected for CMV specificity (via the endogenous TCR; for Line B) or CD8 expression (for Line C), as well as effector memory ($CD62L^-$ $CD45RO^+$ T_{EM}) derived T cells (for line D). These data show that EGFRt can successfully be used as a selection marker for various sources of T cell transductants, even when the original transduction efficiency was as low a 2%.

Inactivity of EGFRt on selected T cells

[0071] To confirm that the EGFRt is inactive, Western immunoblot analyses for EGFR phosphorylation were carried out on the EGFRt-selected T cells after culture with either EGF or cetuximab. As expected, cetuximab did not induce EGFR phosphorylation above background even in the $EGFR^+$ cell line A431 (Fig 3a). Furthermore, in contrast to that seen with the A431 cells, no phosphorylation was seen in lysates of Line A after co-incubation with EGF. Indeed, using biotinylated EGF, flow cytometric analysis confirmed that EGF cannot bind the EGFRt-selected T cells (Fig. 3b), as expected due to the truncation in its N-terminus. These $EGFRt^+$ T

cells were also not recognized by another anti-EGFR antibody distinct from cetuximab.

Maintenance of effector phenotype in expanded EGFRt$^+$ CD19CAR$^+$ T cells

[0072] Directly after AutoMACS™ separation, the selected T cells were expanded 30-fold or greater within 12 days after REM stimulation with OKT3, irradiated PBMC feeders and LCL, IL-2 and IL-15 (Fig. 4a). Flow cytometric analysis of the resulting expanded EGFRt$^+$ T cells further confirmed that that they express the CD19CAR and T cell markers such as CD8, TCR, CD3, perforin, granzyme, etc. (Fig. 4b). Furthermore, CD19CAR-directed cytotoxic activity of these EGFRt-selected lines is evident in chromium release assays using CD19-expressing tumor targets (Fig. 4c). A direct comparison of the CD19-specific reactivity of Line E versus its non-selected or 'parental' counterpart shows that there is enhanced CD19CAR-mediated cytotoxicity upon EGFRt-selection. In addition, the CMV-specific T_{CM}-derived CD19CAR$^+$EGFRt$^+$ Line B cells also show cytotoxic activity through their endogenous T cell receptor against targets expressing CMV-pp65 antigen.

[0073] For the CD19CAR$^+$EGFRt$^+$IMPDH2dm$^+$ Line E, the ability of the inosine monophosphate dehydrogenase 2 double mutant (IMPDH2dm) to confer resistance to the IMPDH2-inhibitor mycophenolic acid (MPA; a common immunosuppressant used to prevent rejection in organ transplantation) was also tested. Upon culture in 1uM MPA, the survival and/or proliferation of Line E cells is not inhibited (Fig. 4d). This is in contrast to the inhibition seen with a control T cell line that lacks expression of the IMPDH2dn gene. These data provide further evidence that EGFRt-mediated

selection results in the corresponding selection of the other genes present in the lentiviral construct used to transduce T cells.

Tracking of EGFRt$^+$ T cells in vivo

[0074] To test the potential for detecting in vivo engrafted T cells, bone marrow cells collected from mice that had been engrafted with CD19CAR$^+$EGFRt$^+$ Line C was analyzed by flow cytometry using biotinylated cetuximab (Fig. 5). Control mice that did not receive T cells revealed that there was some cross-reaction of the cetuximab against murine EGFR. Thus, it was determined that successful detection of engrafted Line C cells required double staining for both human CD45 and EGFRt. Cells may also analyzed using immunohistochemistry to determine potential for screening biopsy material.

Cetuximab mediated cytotoxicity of EGFRt$^+$ T cells

[0075] Because cetuximab is known to lyse EGFR-expressing cells via antibody dependent cell mediated cytotoxicity (ADCC), assays were performed to determine the ADCC activity of cetuximab against EGFRt$^+$ T cells (Fig. 6). Using ^{51}Cr-labeled Line A cells as targeted and freshly isolated human PBMC as effectors, cetuximab was found to significantly mediate chromium-release above that seen when using the CD20-specific humanized mAb Rituxan.

Example of therapeutic use of EGFRt$^+$ T cells

[0076] Adult subjects with high-risk intermediate grade B-cell lymphomas who are candidates for an autologous myeloablative stem cell transplant procedure may receive post-transplant immunotherapy with adoptively transferred autologous Tcm-derived CD19R$^+$ CD8$^+$ EGFRt$^+$ T cell grafts. A leukapheresis product collected from each patient undergoes selection of Tcm, transduction with clinical grade CD19CAR-

T2A-EGFRt_epHIV7, and then selection and expansion of the EGFRt$^+$ cells in a closed system. After the resulting cell products have undergone quality control testing (including sterility and tumor specific cytotoxicity tests), they are cryopreserved. Meanwhile, following leukapheresis, study participants commence with standard salvage chemotherapy, with mobilization for auto HSC collection with cytoreductive chemotherapy and G-CSF. Since the EGFRt-selected, CD19-specific T cells will also target normal CD20$^+$ (CD19$^+$) B cells, the B cell numbers can first be lowered using Rituximab™ to reduce the recipient's inflammatory response upon receiving the genetically modified CTL and also increase availability of infused T cells to immediately target lymphoma cells. Furthermore, Rituximab™ may blunt a humoral immune response against the genetically modified T cells. If Rituximab™ is not given as part of the Salvage/Priming chemotherapy regimen, research participants may receive a single intravenous infusion of Rituximab™ (chimeric anti-CD20 antibody) at 375 mg/m^2 within 4-weeks of the planned auto-HSCT procedure. Rituximab™ infusion would be carried out per standard practice including premedication with diphenhydramine and acetaminophen and hydrocortisone. On Day +2 or Day +3 after HSCT, the autologous cryopreserved CD19R$^+$ CD8$^+$ EGFRt$^+$ T cell product will be transported, thawed and infused at the patient's bedside. Research participants can be pre-medicated at least 30 minutes prior to T cell infusion with 15mg/kg of acetaminophen P.O. (max. 650mg.) and diphenhydramine 0.5-1 mg/kg I.V. (max dose 50mg). Clinical and laboratory correlative follow-up studies can then be performed at the physician's discretion, and may include quantitative RT-PCR studies for the presence of CD19-expressing lymphoma cells and/or the adoptively transfered T cells; FDG-PET and/or CT scans;

bone marrow examination for disease specific pathologic evaluation; lymph node biopsy; and/or long-term follow up per the guidelines set forth by the FDA's Biologic Response Modifiers Advisory Committee that apply to gene transfer studies. Figure 10 provides a possible schematic for clinical testing of the present products and methods.

[0077] The present invention is not to be limited in scope by the specific embodiments disclosed in the examples which are intended as illustrations of a few aspects of the invention and any embodiments that are functionally equivalent are within the scope of this invention. Indeed, various modifications of the invention in addition to those shown and described herein will become apparent to those skilled in the art and are intended to fall within the scope of the appended claims.

[0078] All patents, patent applications, and references cited throughout the specification are expressly incorporated by reference.

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CLAIMS

1. A modified EGFR gene, comprising an EGFR Domain III and an EGFR Domain IV, but lacking an EGFR Domain I, EGFR Domain II, EGFR Juxtamembrane Domain, and an EGFR Tyrosine Kinase Domain.

2. The gene of claim 1, further comprising a GMCSFR alpha chain signal sequence.

3. The gene of claim 2 comprising SEQ ID NO:2.

4. The gene of claim 2, wherein the gene encodes an amino acid sequence comprising at least 90% identical to SEQ ID NO:3.

5. The gene of claim 2, wherein the gene encodes an amino acid sequence comprising SEQ ID NO:3.

6. The gene of claim 1, wherein the gene is part of a construct which comprises the modified EGFR coupled via a C-terminal 2A cleavable linker to a chimeric antigen receptor specific for a tumor associated antigen selected from CD19, a codon-optimized anti-CD19 costimulatory chimeric antigen receptor (CD19CAR), CD20 or CD22.

7. The gene of claim 6, wherein the modified EGFR is coupled to a CD19CAR and a C-terminal 2A cleavable linker.

8. The gene of claim 7, wherein the gene encodes amino acid sequence of the construct comprising SEQ ID NO:6.

9. The gene of claim 1, comprising nucleotides 67-1071 of SEQ ID NO:2.

10. The gene of claim 1, comprising nucleotides 67-1071 of SEQ ID NO:1.

11. The gene of claim 2 comprising SEQ ID NO:1.

12. A population of human T-cells transfected with a gene according to any one of claims 1 to 9.

13. A population of cells according to claim 12, wherein the gene comprises a nucleotide sequence encoding a truncated non-immunogenic endogenous cell surface molecule, said cell surface molecule comprising an EGFR Domain III and an EGFR Domain IV; but lacking all of the domains consisting of an EGFR Domain I, an EGFR Domain II, an EGFR Juxtamembrane Domain, and an EGFR Tyrosine Kinase Domain; wherein the truncated non-immunogenic endogenous cell surface molecule (i) does not have endogenous signaling or trafficking function; (ii) binds a therapeutic anti-EGFR antibody; and (iii) does not bind an endogenous EGFR ligand; and optionally, (iv) acts as a marker.

14. The T-cells according to claim 13, wherein the genetically modified EGFR gene encodes an amino acid sequence comprising residues 23-357 of SEQ ID NO:3.

15. The T-cells according to any one of claims 13 or 14, wherein the therapeutic anti-EGFR antibody is cetuximab.

16. The T-cells according to any one of claims 12 to 15, wherein said gene is inserted into a vector to transfect the population of human T-cells.

17. An in vitro method of enriching or selecting the T-cells according to any one of claims 12 to 16, comprising contacting the T-cells with an antibody that recognizes the truncated non-immunogenic endogenous cell surface molecule.

18. An in vitro method of enriching or selecting the T-cells of claim 13, wherein said T cells are transfected with a genetically modified Epidermal Growth Factor Receptor (EGFR) gene that is coupled to a CD19CAR and a C-terminal 2A cleavable linker, wherein the T-cells encode an amino acid sequence comprising SEQ ID NO:6, comprising contacting the T-cells with an antibody that recognizes the truncated non-immunogenic endogenous cell surface molecule.

19. A method of depleting the T-cells of claim 13 in vivo, wherein said T cells are transfected with a genetically modified Epidermal Growth Factor Receptor (EGFR) gene that is coupled to a CD19CAR and a C-terminal 2A cleavable linker, wherein the T-cells encode an amino acid sequence comprising SEQ ID NO:6, comprising contacting the T-cells with an antibody that recognizes the truncated non-immunogenic endogenous cell surface molecule.

City of Hope

Patent Attorneys for the Applicant/Nominated Person

SPRUSON & FERGUSON

Figure 1

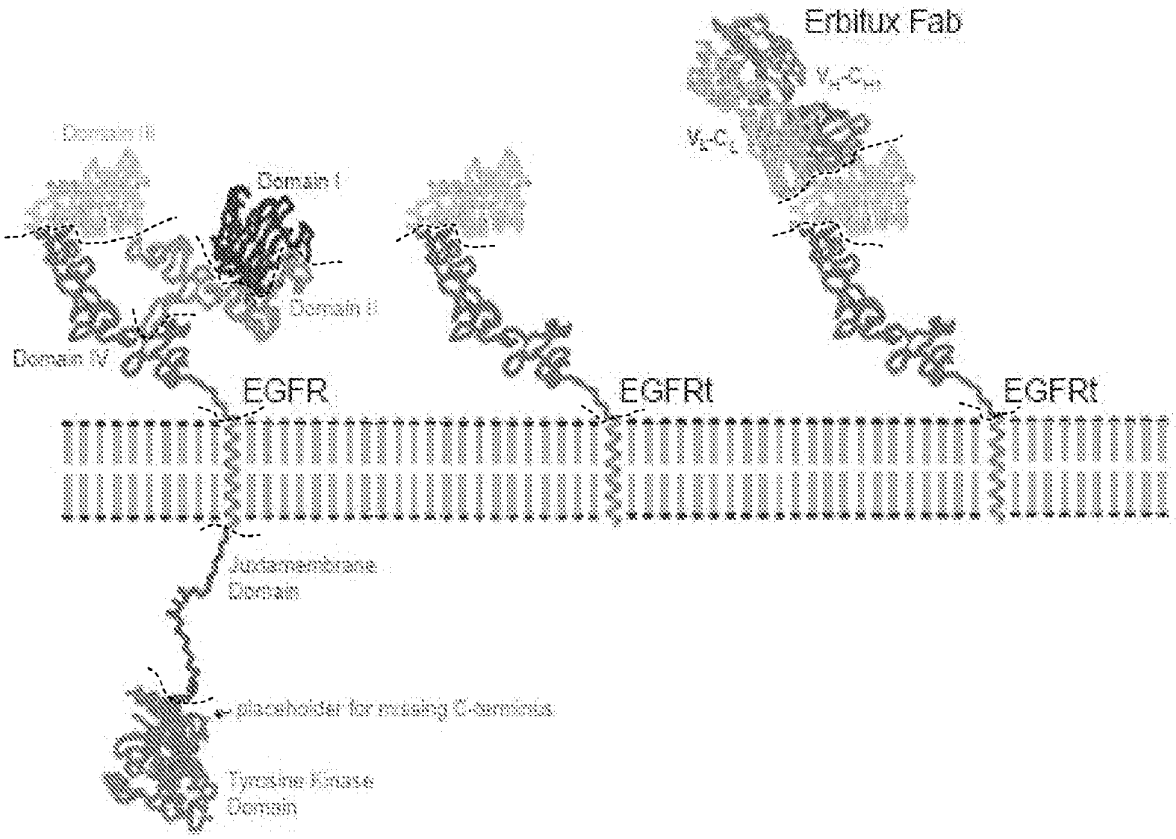

Erbitux Fab
Domain II
Domain I
Domain III
Domain IV
EGFR
EGFRt
EGFRt
Juxtamembrane Domain
placeholder for missing C-terminus
Tyrosine Kinase Domain

Figure 2A

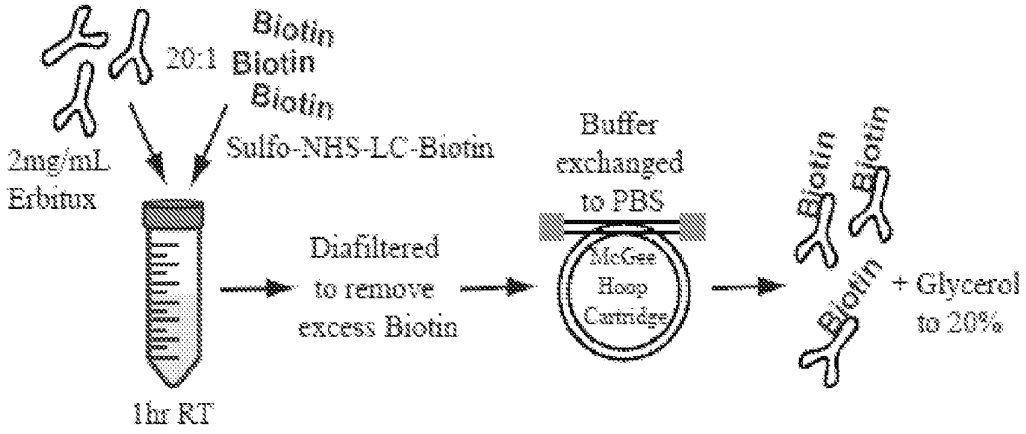
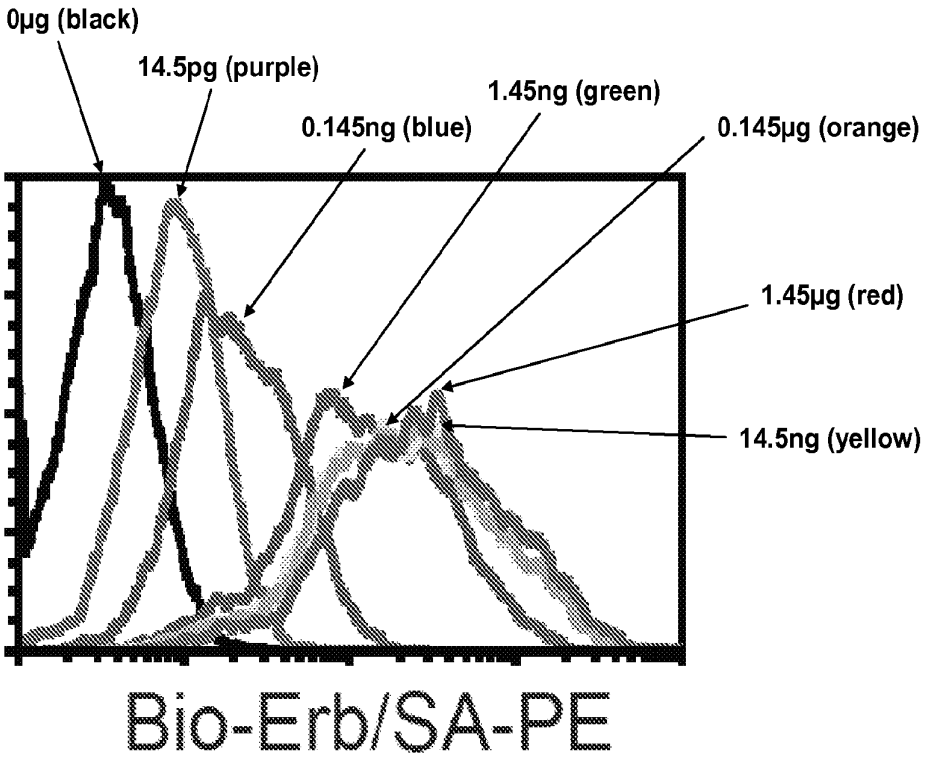

Biotin
Biotin
Biotin
20:1
2mg/mL
Erbitux
Sulfo-NHS-LC-Biotin
1hr RT
Diafiltered
to remove
excess Biotin
Buffer
exchanged
to PBS
McGee
Hoop
Cartridge
Biotin
Biotin
Biotin
+ Glycerol
to 20%

Figure 2B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14.5pg (purple)
1.45ng (green)
0.145ng (blue)
0.145µg (orange)
1.45µg (red)
14.5ng (yellow)
Bio-Erb/SA-PE

Figure 2C

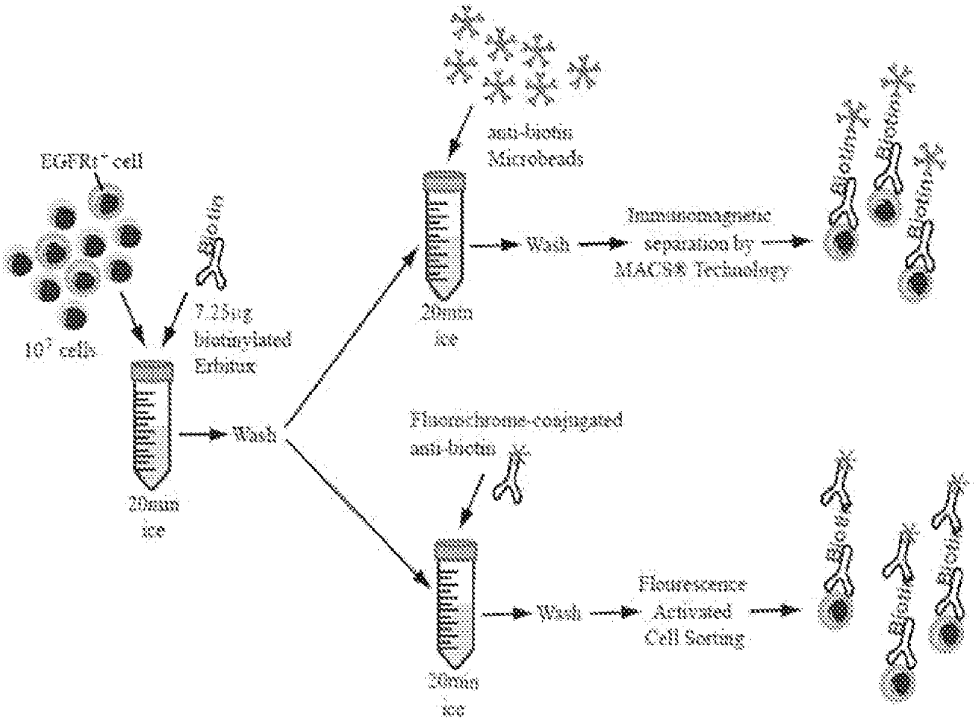
EGFR+ cell
10^7 cells
7.25ug biotinylated Erbitux
20min ice
Wash
anti-biotin Microbeads
20min ice
Wash
Immunomagnetic separation by MACS® Technology
Fluorochrome-conjugated anti-biotin
20min ice
Wash
Flourescence Activated Cell Sorting

Figure 2D

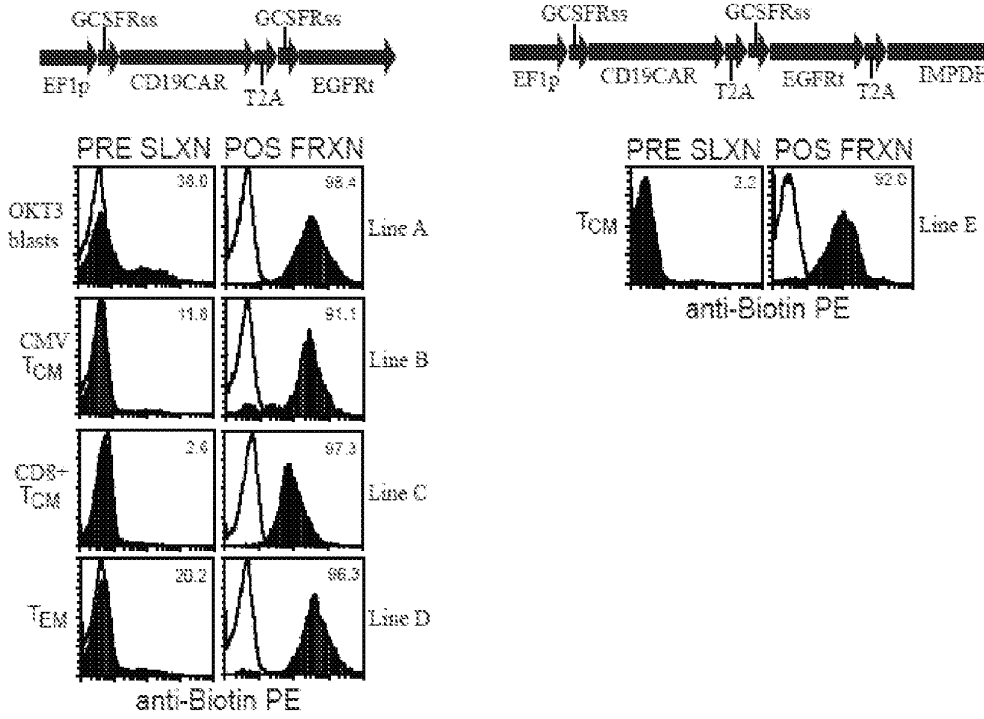
GCSFRss
GCSFRss
EF1p
CD19CAR
T2A
EGFRt
PRE SLXN POS FRXN
OKT3 blasts
38.0
98.4
Line A
CMV TCM
11.6
91.1
Line B
CD8+ TCM
2.6
97.3
Line C
TEM
20.2
86.3
Line D
anti-Biotin PE
GCSFRss
GCSFRss
EF1p
CD19CAR
T2A
EGFRt
T2A
IMPDH2dm
PRE SLXN POS FRXN
TCM
3.2
92.0
Line E
anti-Biotin PE

Figure 3A

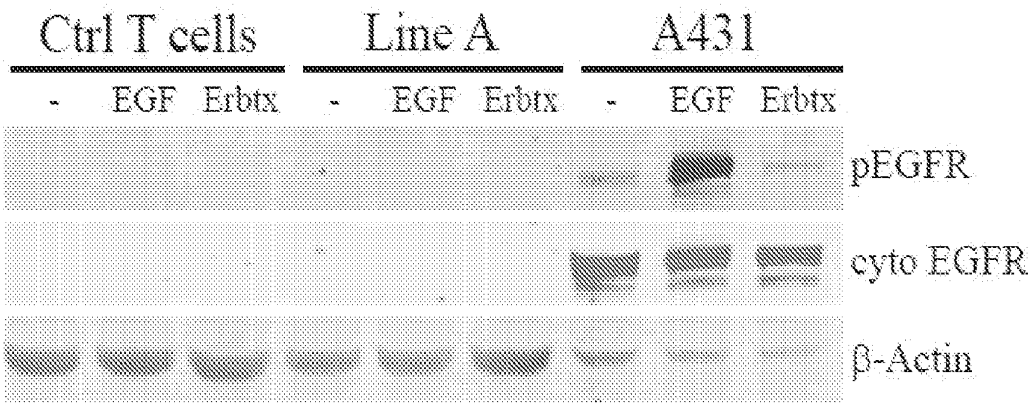
Ctrl T cells
Line A
A431
- EGF Erbtx - EGF Erbtx - EGF Erbtx
pEGFR
cyto EGFR
β-Actin

Figure 3B

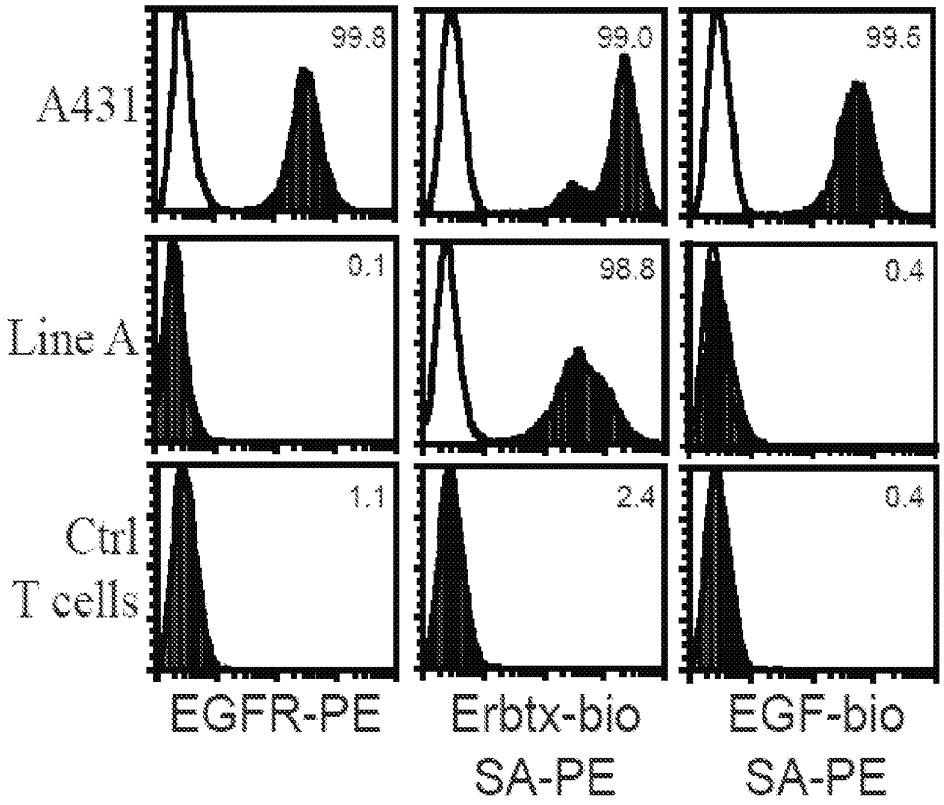
A431
Line A
Ctrl
T cells
99.8
99.0
99.5
0.1
98.8
0.4
1.1
2.4
0.4
EGFR-PE
Erbtx-bio
SA-PE
EGF-bio
SA-PE

Figure 4A

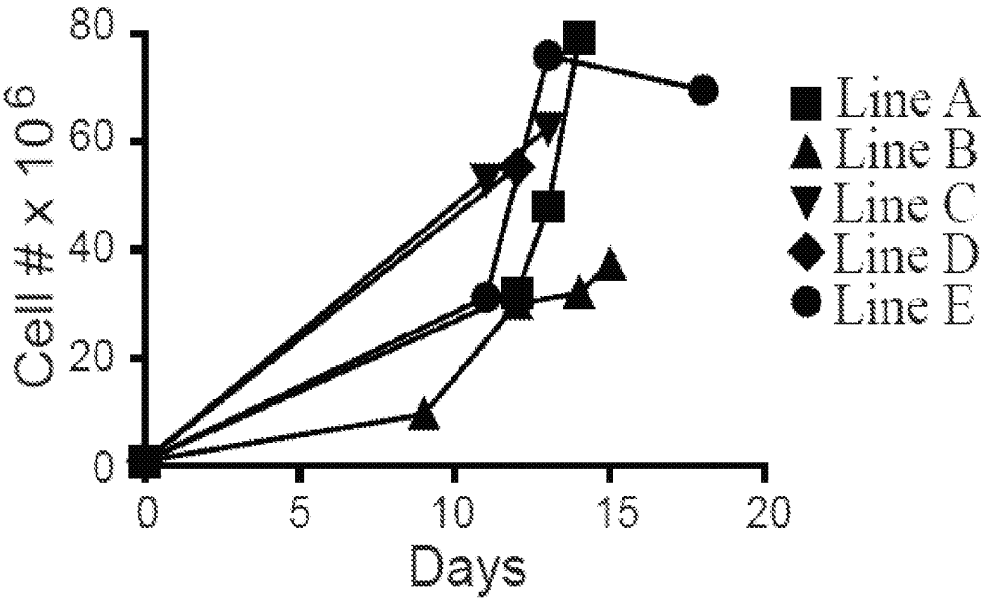
80
60
40
20
0
Cell # x 10^6
0
5
10
15
20
Days
Line A
Line B
Line C
Line D
Line E

Figure 4B

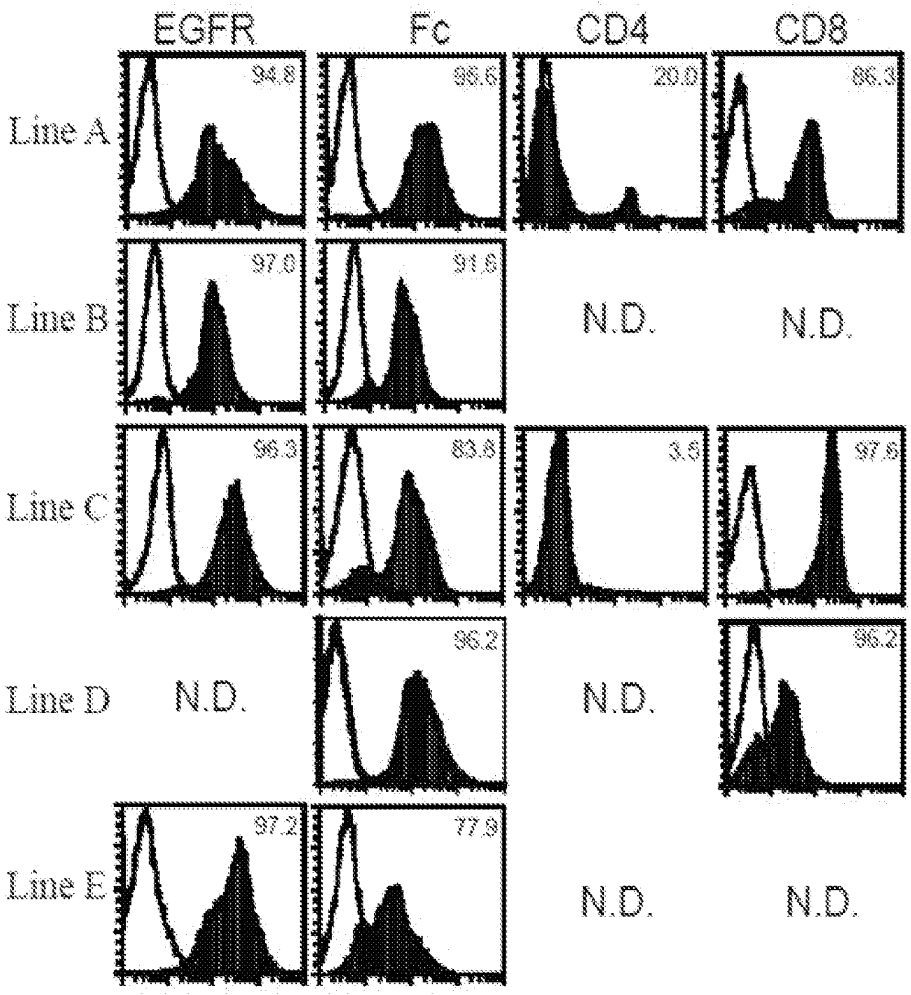
EGFR
Fc
CD4
CD8
Line A
94.8
86.6
20.0
86.3
Line B
97.8
91.6
N.D.
N.D.
Line C
96.3
83.6
3.6
97.6
Line D
N.D.
96.2
N.D.
96.2
Line E
97.2
77.9
N.D.
N.D.

Figure 4C

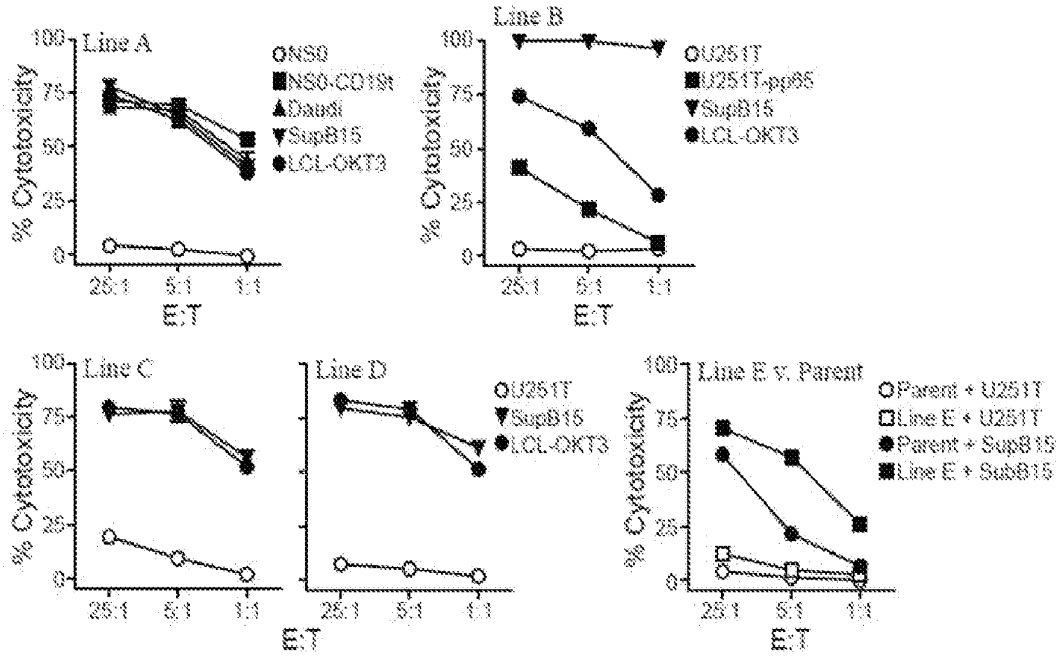
Line A
NS0
NS0-CD19t
Daudi
SupB15
LCL-OKT3
% Cytotoxicity
E:T
Line B
U251T
U251T-pp65
SupB15
LCL-OKT3
Line C
U251T
SupB15
LCL-OKT3
Line D
U251T
SupB15
LCL-OKT3
Line E v. Parent
Parent + U251T
Line E + U251T
Parent + Sup815
Line E + SubB15

Figure 4D

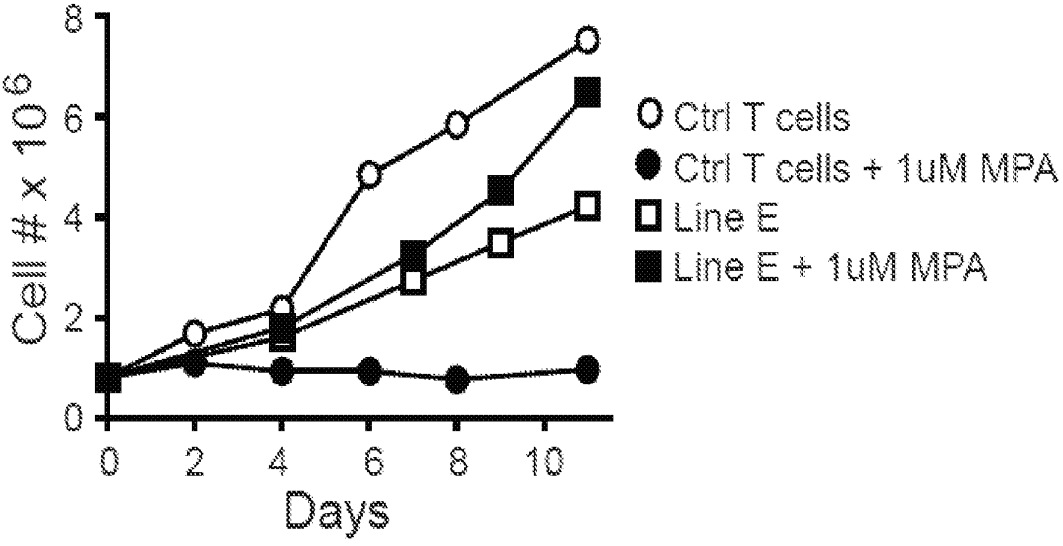
Cell # x 10^6
0
2
4
6
8
0
2
4
6
8
10
Days
Ctrl T cells
Ctrl T cells + 1uM MPA
Line E
Line E + 1uM MPA

Figure 5

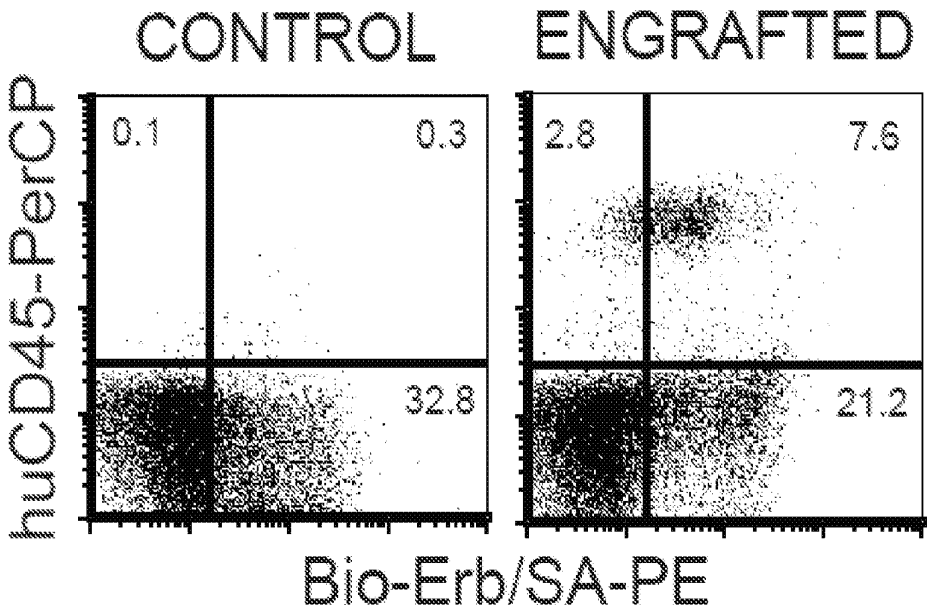
CONTROL
ENGRAFTED
huCD45-PerCP
0.1
0.3
32.8
2.8
7.6
21.2
Bio-Erb/SA-PE

Figure 6

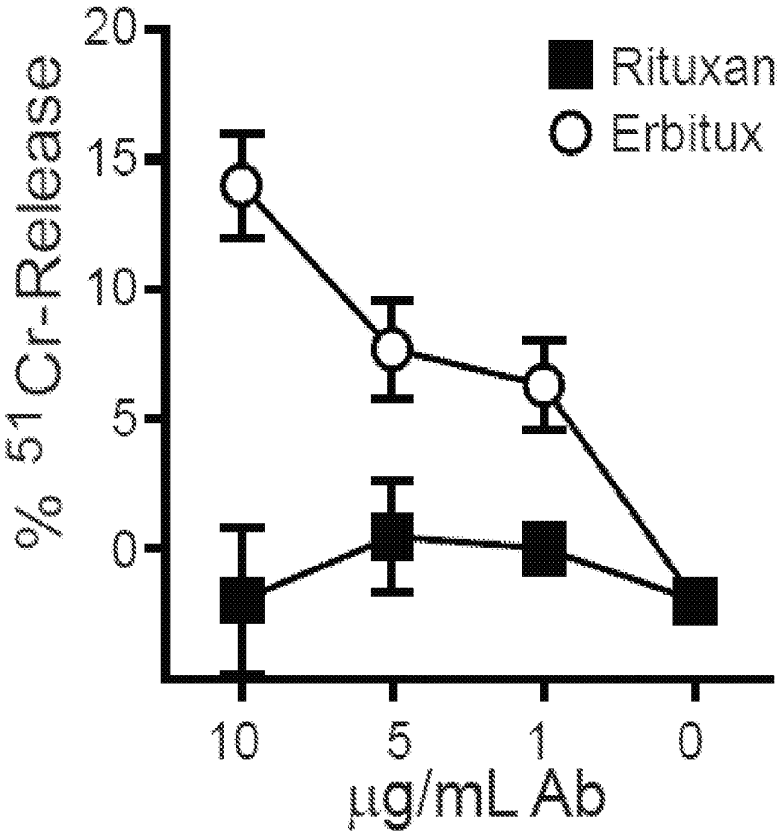

Figure 7

```
      M  L  L  L  V  T  S  L  L  L  C  E  L  P  H  P  A  F  L  L
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      TACGAAGAGG ACCACTGTTC GGAAGACGAG ACACTCAATG GTGTGGGTCG TAAGGAGGAC
      I  P  R  K  V  C  N  G  I  G  I  G  E  F  K  D  S  L  S  I
   61 ATCCCACGCA AAGTGTGTAA CGGAATAGGT ATTGGTGAAT TTAAAGACTC ACTCTCCATA
      TAGGGTGCGT TTCACACATT GCCTTATCCA TAACCACTTA AATTTCTGAG TGAGAGGTAT
      N  A  T  N  I  K  H  F  K  N  C  T  S  I  S  G  D  L  H  I
  121 AATGCTACGA ATATTAAACA CTTCAAAAAC TGCACCTCCA TCAGTGGCGA TCTCCACATC
      TTACGATGCT TATAATTTGT GAAGTTTTTG ACGTGGAGGT AGTCACCGCT AGAGGTGTAG
      L  P  V  A  F  R  G  D  S  F  T  H  T  P  P  L  D  P  Q  E
  181 CTGCCGGTGG CATTTAGGGG TGACTCCTTC ACACATACTC CTCCTCTGGA TCCACAGGAA
      GACGGCCACC GTAAATCCCC ACTGAGGAAG TGTGTATGAG GAGGAGACCT AGGTGTCCTT
      L  D  I  L  K  T  V  K  E  I  T  G  F  L  L  I  Q  A  W  P
  241 CTGGATATTC TGAAAACCGT AAAGGAAATC ACAGGGTTTT TGCTGATTCA GGCTTGGCCT
      GACCTATAAG ACTTTTGGCA TTTCCTTTAG TGTCCCAAAA ACGACTAAGT CCGAACCGGA
      E  N  R  T  D  L  H  A  F  E  N  L  E  I  I  R  G  R  T  K
  301 GAAAACAGGA CGGACCTCCA TGCCTTTGAG AACCTAGAAA TCATACGCGG CAGGACCAAG
      CTTTTGTCCT GCCTGGAGGT ACGGAAACTC TTGGATCTTT AGTATGCGCC GTCCTGGTTC
      Q  H  G  Q  F  S  L  A  V  V  S  L  N  I  T  S  L  G  L  R
  361 CAACATGGTC AGTTTTCTCT TGCAGTCGTC AGCCTGAACA TAACATCCTT GGGATTACGC
      GTTGTACCAG TCAAAAGAGA ACGTCAGCAG TCGGACTTGT ATTGTAGGAA CCCTAATGCG
      S  L  K  E  I  S  D  G  D  V  I  I  S  G  N  K  N  L  C  Y
  421 TCCCTCAAGG AGATAAGTGA TGGAGATGTG ATAATTTCAG GAAACAAAAA TTTGTGCTAT
      AGGGAGTTCC TCTATTCACT ACCTCTACAC TATTAAAGTC CTTTGTTTTT AAACACGATA
      A  N  T  I  N  W  K  K  L  F  G  T  S  G  Q  K  T  K  I  I
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      CGTTTATGTT ATTTGACCTT TTTTGACAAA CCCTGGAGGC CAGTCTTTTG GTTTTAATAT
      S  N  R  G  E  N  S  C  K  A  T  G  Q  V  C  H  A  L  C  S
  541 AGCAACAGAG GTGAAAACAG CTGCAAGGCC ACAGGCCAGG TCTGCCATGC CTTGTGCTCC
      TCGTTGTCTC CACTTTTGTC GACGTTCCGG TGTCCGGTCC AGACGGTACG GAACACGAGG
      P  E  G  C  W  G  P  E  P  R  D  C  V  S  C  R  N  V  S  R
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      GGGCTCCCGA CGACCCCGGG CCTCGGGTCC CTGACGCAGA GAACGGCCTT ACAGTCGGCT
      G  R  E  C  V  D  K  C  N  L  L  E  G  E  P  R  E  F  V  E
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  721 AACTCTGAGT GCATACAGTG CCACCCAGAG TGCCTGCCTC AGGCCATGAA CATCACCTGC
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      T  G  R  G  P  D  N  C  I  Q  C  A  H  Y  I  D  G  P  H  C
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      V  K  T  C  P  A  G  V  M  G  E  N  N  T  L  V  W  K  Y  A
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      CAGTTCTGGA CGGGCCGTCC TCAGTACCCT CTTTTGTTGT GGGACCAGAC CTTCATGCGT
      D  A  G  H  V  C  H  L  C  H  P  N  C  T  Y  G  C  T  G  P
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      G  L  E  G  C  P  T  N  G  P  K  I  P  S  I  A  T  G  M  V
  961 GGTCTTGAAG GCTGTCCAAC GAATGGGCCT AAGATCCCGT CCATCGCCAC TGGGATGGTG
      CCAGAACTTC CGACAGGTTG CTTACCCGGA TTCTAGGGCA GGTAGCGGTG ACCCTACCAC
      G  A  L  L  L  L  L  V  V  A  L  G  I  G  L  F  M
 1021 GGGGCCCTCC TCTTGCTGCT GGTGGTGGCC CTGGGGATCG GCCTCTTCAT G
      CCCCGGGAGG AGAACGACGA CCACCACCGG GACCCCTAGC CGGAGAAGTA C
```

Figure 8 CD19R-CD28gg-Zeta(CO)-T2A-EGFRt

```
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      CACTGGTAGT CGACGGCCCG GTCGGTCCTG TAGTCGTTCA TGGACTTGAC CATAGTCGTC
      K  P  D  G  T  V  K  L  L  I  Y  H  T  S  R  L  H  S  G  V
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      GGGTCGGCCA AATCGCCGTC GCCGAGGCCG TGGCTGATGT CGGACTGGTA GAGGTTGGAC
      E  Q  E  D  I  A  T  Y  F  C  Q  Q  G  N  T  L  P  Y  T  F
  301 GAACAGGAAG ATATCGCCAC CTACTTTTGC CAGCAGGGCA ACACACTGCC CTACACCTTT
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      CCGCCGCCTT GTTTCGACCT TTAGTGGCCG TCGTGGAGGC CGTCGCCGTT CGGACCGTCG
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      Y  C  A  K  H  Y  Y  Y  G  G  S  Y  A  M  D  Y  W  G  Q  G
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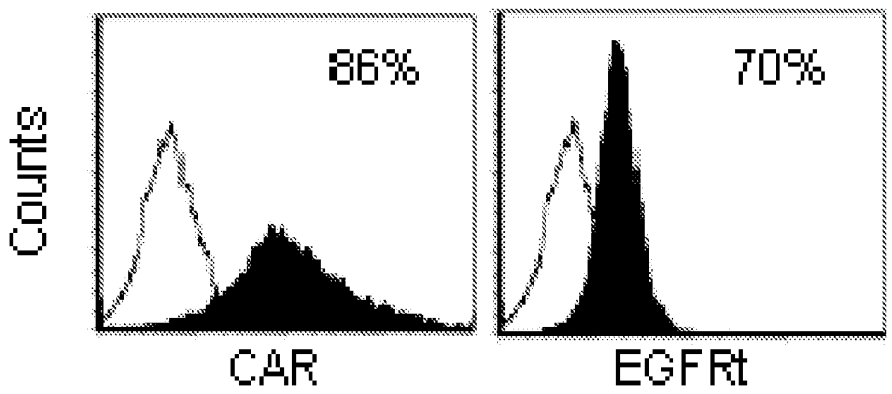
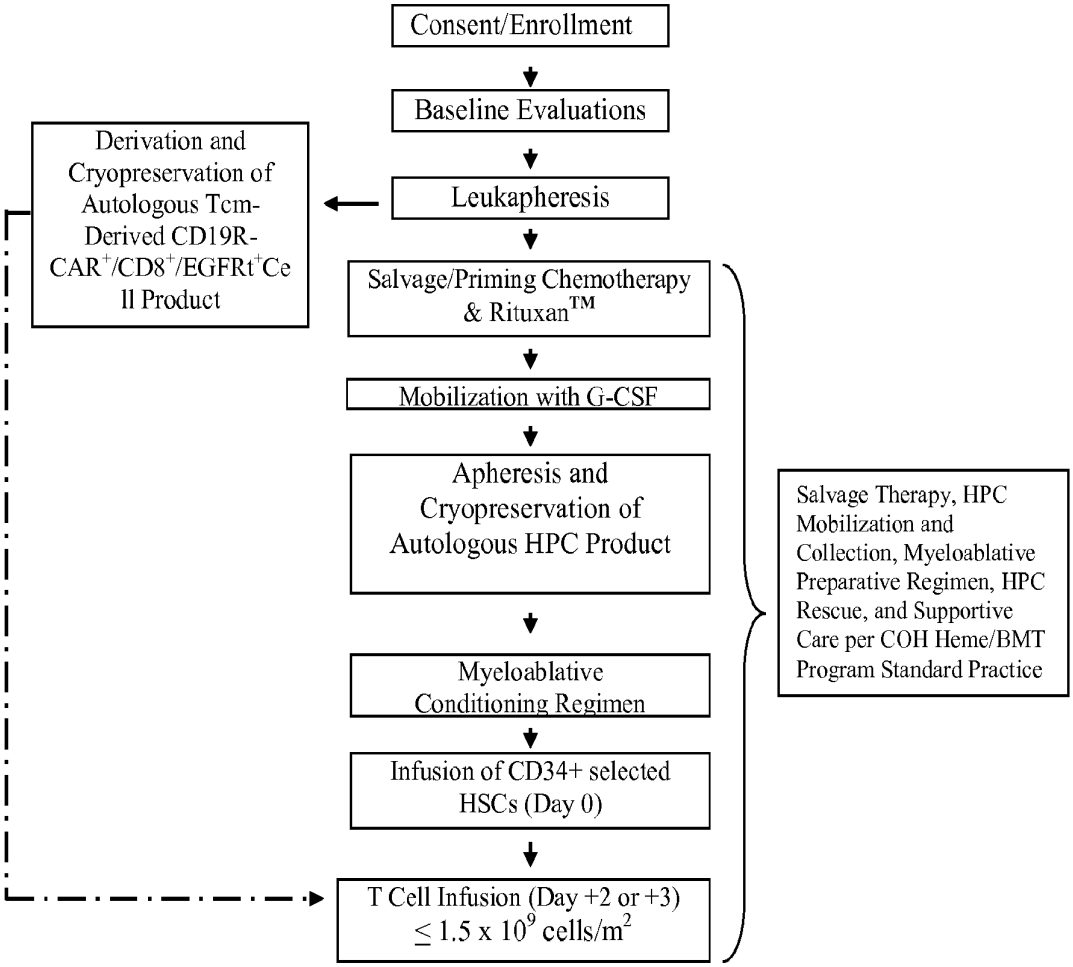


Figure 10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Myeloablative Conditioning Regimen
Infusion of CD34+ selected HSCs (Day 0)
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SEQUENCE LISTING

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