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(54) Titre : RECEPTEUR D'ANTIGENE CHIMERE ET LYMPHOCYTES T A CAR SE LIANT A CXCR5
(54) Title: CHIMERIC ANTIGEN RECEPTOR AND CAR-T CELLS THAT BIND CXCR5

(57) **Abrégé/Abstract:**

The invention relates to an isolated chimeric antigen receptor polypeptide (CAR), wherein the CAR comprises an extracellular antigen-binding domain, comprising an antibody or antibody fragment that binds a human CXC chemokine receptor type 5 (CXCR5) protein. The invention further relates to a nucleic acid molecule encoding the CAR of the invention, a genetically modified immune cell, preferably a T cell, expressing the CAR of the invention and the use of said cell in the treatment of a medical disorder associated with the presence of pathogenic cells expressing CXCR5, preferably pathogenic mature B cells and/or memory B cells, and/or pathogenic T cells and/or T follicular helper cells, in particular mature B cell non-Hodgkin's lymphoma (B-NHL), T cell non-Hodgkin's lymphoma, or autoantibody-dependent autoimmune disease, preferably selected from systemic lupus erythematosus (SLE) or rheumatoid arthritis.

Abstract

The invention relates to an isolated chimeric antigen receptor polypeptide (CAR), wherein the CAR comprises an extracellular antigen-binding domain, comprising an antibody or antibody fragment that binds a human CXC chemokine receptor type 5 (CXCR5) protein. The invention further relates to a nucleic acid molecule encoding the CAR of the invention, a genetically modified immune cell, preferably a T cell, expressing the CAR of the invention and the use of said cell in the treatment of a medical disorder associated with the presence of pathogenic cells expressing CXCR5, preferably pathogenic mature B cells and/or memory B cells, and/or pathogenic T cells and/or T follicular helper cells, in particular mature B cell non-Hodgkin's lymphoma (B-NHL), T cell non-Hodgkin's lymphoma, or autoantibody-dependent autoimmune disease, preferably selected from systemic lupus erythematosus (SLE) or rheumatoid arthritis.

CHIMERIC ANTIGEN RECEPTOR AND CAR-T CELLS THAT BIND CXCR5

DESCRIPTION

5 The invention relates to an isolated chimeric antigen receptor polypeptide (CAR), wherein the CAR comprises an extracellular antigen-binding domain, comprising an antibody or antibody fragment that binds a CXC chemokine receptor type 5 (CXCR5) protein. The invention further relates to a nucleic acid molecule encoding the CAR of the invention, a genetically modified immune cell, preferably a T cell, expressing the CAR of the invention and the use of said cell in the treatment of a medical
10 disorder associated with the presence of pathogenic cells expressing CXCR5, preferably pathogenic mature B cells and/or memory B cells, and/or pathogenic T cells and/or T follicular helper cells, in particular mature B cell non-Hodgkin's lymphoma (B-NHL), T cell non-Hodgkin's lymphoma, or autoantibody-dependent autoimmune disease, preferably selected from systemic lupus erythematosus (SLE) or rheumatoid arthritis.

15 BACKGROUND OF THE INVENTION

B-NHLs are heterogenous and can be distinguished by an aggressive and indolent course. The standard of care is typically combined antibody/chemotherapy, either alone or in combination with autologous stem cell transplantation, immunomodulatory drugs, irradiation, proteasome inhibitors, signaling pathway inhibitors, and for very few patients allogeneic stem cell transplantation applies.
20 Because in many B-NHL entities the median age at diagnosis is >66-72 years, co-morbidities also exist that preclude intense and extended chemotherapies or even allogeneic bone marrow transplantations.

Inhibitors of B cell receptor (BCR) signaling in mature B cell lymphomas, foremost ibrutinib and others, have brought about a tremendous advance in remission rates. Despite initial high sensitivity
25 to these class of kinase inhibitors, it is uncertain whether tumor eradication can be achieved and secondly, several studies revealed that clonal lymphoma and leukemia evolution led to the occurrence of resistance to Bruton tyrosine kinase (BTK) inhibition. Thus, the rapid emergence of secondary resistances to targeted therapies demonstrates the urgent need to find a solution for tolerable salvage therapies, applicable in particular to patients having received several lines of other
30 chemotherapies and thus, with a reduced clinical performance (IPI score).

Adoptive chimeric antigen receptor (CAR)-T cell therapies targeted at the broadly expressed CD19 antigen on leukemia and lymphoma B cells has brought about substantial clinical efficacy and currently, more than 40 CD19 CAR-T cell studies are registered at the FDA for the treatment of B-NHL and B-ALL (www-clinicaltrials.gov). However, in anti-CD19 antibody or CAR-T cell therapies
35 directed against B-NHL, resistance can occur due to antigen loss. A recent study showed that upon anti-CD19 CAR-T cell therapy, escape variants emerged that resulted from the selection for alternatively spliced CD19 isoforms and thus, loss of the cognate CD19 CAR epitope.

Thus, CXCR5 emerges as an alternative target for immunotherapy of B-cell lymphomas besides existing therapeutic mAbs or CAR-T cell therapies.

40 B cell derived lymphoproliferative disorders with distinctive nodal lodging, such as acute lymphoblastic leukemia (B-ALL), chronic lymphocytic leukemia (CLL), follicular lymphoma (FL), mantle cell lymphoma (MCL), diffuse large B-cell lymphoma (DLBCL) frequently express the homeostatic chemokine receptor CXCR5. CXCR5 is physiologically expressed on mature

recirculating B cells and on a small subset of CD4+ T cells, the follicular T-helper cells (Tfh) and regulates their homeostatic trafficking and homing to B-cell follicles within secondary lymphoid organs. Importantly, CXCR5 is not expressed on B cell precursors within the bone marrow (BM), neither do plasma cells express this receptor.

- 5 To the knowledge of the inventors, no alternative anti-CXCR5 CAR constructs have been previously described, and no anti-CXCR5 antibody studies relevant to the medical approach of the present invention are currently available.

Panjideh et al (International Journal of Cancer, vol. 135, no. 11, 29 April 2014) describes the use of a CXCR5 bi-specific antibody for the treatment of non-Hodgkin's lymphoma. Sadelain et al (Cancer
10 Discovery, vol. 3, no. 4, 1 April 2013) present a review of various CAR technologies, without reference to CXCR5. WO 2016/090034 discloses multiple possible targets for CAR constructs. CD185 (CXCR5) is mentioned, without any details regarding CAR components, medical uses or any reference to the relevance of the target. WO 2016/164731 describes the use of CAR-T cells directed against various B cell target antigens. CXCR5 is not mentioned as a CAR T target.

15 Alternative therapies for medical conditions such as those described above are in development or have been recently established, for example anti-CD19 CAR constructs, standard therapies such as cytotoxic chemotherapies, corticosteroids, immunomodulators like IMiDs, proteasome inhibitors, autologous stem cell transplantation, allogeneic stem cell transplantation, signaling inhibitors, and antibodies directed against CD20, Rituximab, and anti-CD19, Oletuzumab and with bispecific
20 antibodies (BITE), comprised of an Fab fragment targeting CD19 and an anti-CD3 fragment (Blinatumomab).

Although a number of potential alternative therapies are in development for diseases of pathogenic B and T cells, a significant need remains for providing effective means for addressing such medical disorders.

25 **SUMMARY OF THE INVENTION**

In light of the prior art the technical problem underlying the invention was the provision of an agent suitable for treating diseases associated with pathogenic B cells and/or T cells, in particular non-Hodgkin's lymphoma or autoantibody-dependent autoimmune diseases.

This problem is solved by the features of the independent claims. Preferred embodiments of the
30 present invention are provided by the dependent claims.

Therefore, the invention relates to a chimeric antigen receptor polypeptide (CAR), comprising:

- i. an extracellular antigen-binding domain, comprising an antibody or antibody fragment that binds CXC chemokine receptor type 5 (CXCR5) protein,
- ii. a transmembrane domain, and
- 35 iii. an intracellular domain.

The present invention therefore relates to an anti-CXCR5 CAR construct and corresponding immune cells expressing said construct, preferably a CAR-T cell product that confers human T cells with a high cytotoxic activity against defined, mature B-NHLs, while sparing normal hematopoietic cells such as T cells (except for Tfh or other T cell lymphomas described herein), plasma B cells and their
40 bone marrow precursors. In preferred embodiments all myeloid cells and NK cells are likewise spared; as the CAR-T cell product of the present invention shows no activity against these cells.

In preferred embodiments of the immunotherapy approach of the present invention, patient-derived T cells are transduced, preferably retrovirally, to express an artificial immune receptor as described herein, composed of an extracellular antibody-derived antigen recognition part, fused to a transmembrane section, and followed by intracellular signaling domains. The construct described
 5 herein therefore confers transduced T cells with anti-tumor cytolytic capacity.

Due to the preferred autologous transfer of T cells, a graft-versus-host-disease cannot occur upon treatment with the CAR-Ts of the present invention. Memory T cell formation, which is important for the prevention of a relapse, can develop.

Such mature B-NHL entities include, but are not limited to, certain stages of follicular lymphoma,
 10 diffuse large B-cell lymphoma, mantle cell lymphoma, and chronic lymphocytic leukemia.

For the first time, the anti-CXCR5 CAR-T cells will enable targeting of the tumor cells in the tumor microenvironment, because lymphoma growth-promoting Tfh cells will be eradicated concomitantly. Tumor cells within a given tumor entity are homogeneously positive for the target antigen CXCR5, thus precluding unwanted positive selection of low/non-expressing tumor cells.

15 The anti-CXCR5 CAR-T cell described herein is in preferred embodiments applicable to the treatment of mature B-NHL patients who are not eligible for other therapies. More specifically, embodiments of the invention relate to the treatment of the following patient collectives:

- i) patients with multidrug resistances,
- ii) patients not eligible for allogeneic stem cell transplantation,
- 20 iii) patients with co-morbidities that preclude further chemotherapies,
- iv) aged patients who do not tolerate chemotherapies,
- v) the CAR is applicable for salvage therapies even after progressive disease and multiple lines of other standard of care therapies have failed,
- vi) it is applicable even at low antigen density on target tumor cells, where antibodies
 25 can fail, and/or
- vii) it is applicable as a monotherapy which is not the case for antibodies.

The anti-CXCR5 CAR described herein confers high avidity to T cells, necessary for anti-tumor efficacy. It has been demonstrated that the anti-CXCR5 CAR of the present invention does not confer T cell-reactivity against physiological plasma B cells, T cells (except for Tfh cells and specific
 30 pathological CXCR5-expressing T-cells), NK cells, all myeloid cell lineages and their precursors. Thus, the present invention has an unprecedented low off-target reactivity on other hematopoietic tissues.

In contrast to anti-CD19 CAR-T cells, the anti-CXCR5 CAR of the present invention has no unwanted reactivity against immature B-NHLs, precursor B-cell neoplasia or physiological benign B-
 35 cell precursors.

As demonstrated in the examples below, in an in vitro co-culture system, anti-CXCR5 CAR-T cells become activated upon exposure to CXCR5-expressing human B-NHL tumor cell lines. These T cells then develop an effector phenotype with high level secretion of IFN-gamma, a phenotype that is predictive of a cytotoxic activity.

Additionally, a cytotoxicity assay (51Cr-release) against selected target cell lines, B-NHL, B and T cell leukemia, CXCR5-negative cells and CXCR5-transfectants, shows that selective cellular cytotoxicity is obtained only in cell lines positive for CXCR5.

Additional pre-clinical testing encompasses i) in vitro cytotoxicity testing against suitable B-NHL cell lines from patients, and ii) in vivo testing of anti-CXCR5 CAR activity against xenotransplanted B-NHL cell lines.

As such, the CAR of the present invention represents a surprising and beneficial approach towards the treatment of the medical conditions described herein. The employment of anti-CXCR5 CARs has not been previously attempted or described as a promising approach towards treating NHL. The minimal (if not non-existent) unwanted side effects, due to the selectivity of the marker, also represent a beneficial and surprising aspect of the present invention. In particular in patients, in which resistance to anti-CD19 treatments have arisen, the present invention represents a very promising approach towards eradication of malignancies.

In one embodiment, the invention relates to a chimeric antigen receptor (CAR) polypeptide as described herein, wherein when said CAR is expressed in a genetically modified immune cell, preferably a T lymphocyte, said immune cell binds CXCR5 on the surface of a CXCR5-expressing cell and is activated, thereby inducing cytotoxic activity against said CXCR5-expressing cell.

Examples of CXCR5-expressing cells are known to a skilled person, and can be identified by further screening of cancers or other pathogenic cells. Cell lines expressing CXCR5 are preferably DOHH-2, OCI-Ly7, SU-DHL4, JeKo-1, JVM-3, MEC-1 and/or SC-1.

In one embodiment, the invention relates to a chimeric antigen receptor polypeptide (CAR), comprising:

- an extracellular antigen-binding domain, comprising an antibody or antibody fragment that binds CXC chemokine receptor type 5 (CXCR5) protein, wherein said antibody or antibody fragment comprises VH and VL domains of a single chain antibody fragment, wherein preferably a linker polypeptide is positioned between the VH and VL domains, wherein said linker is preferably configured to not interfere with the antibody fragment-CXCR5 antigen interaction;
- a spacer polypeptide (also referred to as a hinge) positioned between the extracellular antigen-binding domain and a transmembrane domain, wherein said spacer polypeptide is preferably configured to not interfere with the antibody fragment-CXCR5 antigen interaction and/or with T cell activation when said CAR is expressed in a T cell expressing said CAR;
- a transmembrane domain, wherein said transmembrane domain is preferably configured to not interfere with the antibody fragment-CXCR5 antigen interaction and/or with T cell activation when said CAR is expressed in a T cell expressing said CAR;
- and an intracellular domain, wherein said intracellular domain comprises a co-stimulatory domain and a signalling domain, wherein said intracellular domain is preferably configured to provide signals to stimulate T cell activation upon binding to the CXCR5 target, for example by increasing cytokine production and/or facilitating T cell replication, thus leading to cytotoxic effect.

The CAR of the present invention may therefore employ various formats, comprising potentially different protein sequences for each of the functional domains described herein. A skilled person is capable of selecting and testing the desired function of the CARs, for example based on the

experimental approaches demonstrated in the examples below. As such, the election of any given specific protein sequence to be used in the CAR of the invention, in any of the functional domains discussed herein, can be assessed by a skilled person using routine methods for functional efficacy. For example, various linker polypeptide sequences positioned between the VH and VL domains, various spacer polypeptide sequences (also referred to as a hinge) positioned between the extracellular antigen-binding domain and a transmembrane domain, various transmembrane domains and various intracellular domains, preferably comprising co-stimulatory and signalling domains, may be employed.

In embodiments of the invention, the CAR, and each of the elements or domains mentioned herein, are configured to not detrimentally interfere with the antibody fragment-CXCR5 antigen interaction, to not detrimentally interfere with T cell activation when said CAR is expressed in a T cell expressing said CAR, and to not detrimentally interfere with the CAR providing signals to stimulate T cell activation upon binding to the CXCR5 target.

Experimental approaches are described herein for assessing these properties of a CXCR5 CAR, such that the invention is considered to encompass various functional sequence variants and combinations of domains of the types described herein, without being limited to the particular sequences disclosed by way of example in the following. For example, specific activation of CAR-T cells of the present invention by CXCR5-expressing tumor cells can be demonstrated by the release of IFN-gamma, IL-2 and TNF-alpha, as shown below.

To the knowledge of the inventors, the present invention relates to the first described CXCR5 CAR, and first functional evidence of a desired therapeutic effect of a CXCR5 CAR in a medical setting. Alone the provision of a CXCR5 CAR, independent of the particular sequences employed in the various functional domains described herein, represents a significant and beneficial breakthrough in treating the many diseases associated with pathogenic mature B cells and/or memory B cells, and/or pathogenic T cells and/or T follicular helper cells.

Embodiments relating to the antigen-binding domain of the CAR:

In one embodiment, the invention relates to a chimeric antigen receptor (CAR) polypeptide as described herein, wherein the antigen-binding domain comprises a variable heavy chain (VH), said VH comprising:

- a heavy chain complementary determining region 1 (H-CDR1) with at least 80% sequence identity to SEQ ID NO 1 (GFTFSTSG),
- a heavy chain complementary determining region 2 (H-CDR2) with at least 80% sequence identity to SEQ ID NO 2 (ISSSSGFV), and
- a heavy chain complementary determining region 3 (H-CDR3) with at least 80% sequence identity to SEQ ID NO 3 (ARSEAAF),

and a variable light chain (VL), said VL comprising:

- a light chain complementary determining region 1 (L-CDR1) with at least 80% sequence identity to SEQ ID NO 4 (KSRLSRMGITP),
- a light chain complementary determining region 2 (L-CDR2) with at least 66% sequence identity to SEQ ID NO 5 (RMS), and
- a light chain complementary determining region 3 (L-CDR3) with at least 80% sequence identity to SEQ ID NO 6 (AQFLEYPPT).

In one embodiment, the invention relates to a chimeric antigen receptor (CAR) polypeptide as described herein, comprising a VH domain that comprises CDR sequences of SEQ ID NO. 1, SEQ ID NO. 2 and SEQ ID NO. 3, and a VL domain that comprises CDR sequences of SEQ ID NO. 4; SEQ ID NO 5, and SEQ ID NO. 6.

- 5 In preferred embodiments, the sequence variants with 80% or more sequence identity to the specific CDR sequences of SEQ ID 1-6 maintain CXCR5 binding with essentially the same or similar functional properties as VH and VL domains with the specific CDR sequences of SEQ ID NO 1-6, i.e. the CXCR5 binding is essentially the same or similar with respect to affinity, specificity and epitope binding mode.

- 10 The amino acid sequence of the scFV fragment was obtained originally from a rat-anti-human CXCR5 antibody and has been modified with respect to multiple improvements, for example by humanization of the VL and VH chains, in order to allow folding and expression in the context of a transmembrane receptor structure.

- 15 Furthermore, the order of the light and heavy chain fragments may be inverted upon the desired configuration of the antigen binding fragment.

Additionally, in some embodiments the linker sequence between heavy and light chains has been modified, for example by shortening, in order to enhance the CAR function.

Additionally, the nucleic acid sequence encoding the CAR has been codon-optimized in order to improve expression of the CAR.

- 20 These modifications enable sufficient surface expression on T cells and still maintain proper antigen binding. High affinity and high avidity enable CAR-T cells to i) recognize, ii) be activated against, and iii) kill tumor target cells with high, intermediate or low CXCR5 surface expression.

To the knowledge of the inventors, neither anti-CXCR5 CARs nor humanized anti-CXCR5 antibodies have been previously described in the art.

- 25 Due to the high affinity and avidity of the antigen-binding domain of the anti-CXCR5 CAR-T cell described herein, even low CXCR5-expressing mature B-NHLs can be recognized, allowing for T cell activation and tumor cell killing.

The anti-CXCR5 CAR-T cell product described herein is characterised by unique properties.

- 30 The anti-CXCR5 CAR as described herein has a high affinity and confers high specificity and avidity to T cells. These properties enable CAR-T cells to i) recognize, ii) be activated against, and iii) kill tumor target cells with high and low CXCR5 surface expression.

- 35 The number of CXCR5 antigens expressed on the surfaces of tumor cells can be quantified by using an anti-CXCR5 antibody coupled to a fluorescent-dye in conjunction with Quantibrite beads (from Becton Dickinson). The preferred method applied to quantify CXCR5 antigens expressed on the surfaces of tumor cells is "fluorescence activated cell sorting/cell analysis" (FACS). Fluorescence intensity of beads correlates exactly with the numbers of fluorescent antibodies bound to cells, and this is a measure for the number of CXCR5 molecules on cells.

- 40 The VH and VL fragments described herein may be arranged in multiple configurations in the CAR and still maintain high specificity and high affinity for the target epitope. In some embodiments, the CAR may be configured in the VH-VL or VL-VH configuration, with variation in the linker, hinge, transmembrane domain, co-stimulatory domain and/or activation domains, and still maintain its efficacy. This surprising feature of the invention enables greater flexibility in the design of CARs

directed against CXCR5, thereby enabling further modification and/or optimization of the CAR structure on the basis of the VH and VL domains described herein, if any further development should be necessary or desired.

Sequence alignments of the rat and humanized sequences are shown in Fig. 4. Accordingly, the sequences below also encompass generalized sequences representing both rat and humanized forms of the antigen-binding domains. In the sequence below, each X represents a potential amino acid change. Preferred amino acid substitutions are those described for each of the potentially altered positions.

All possible combinations of potential modifications for any given potentially variant residue proposed herein (as identified by X in the “generalized sequences”) are encompassed by the present invention. By combining one or more of these various substitutions, humanized variants may be generated that exhibit the desired binding properties of the rat antigen-binding domain demonstrated herein. The CARs or parts thereof described herein also encompass a sequence with at least 70%, 80%, preferably 90%, sequence identity to those humanized sequences disclosed explicitly or disclosed through a sequence formula.

In one embodiment, the invention relates to a chimeric antigen receptor (CAR) polypeptide as described herein, comprising a VH domain with at least 70%, 80% sequence identity, preferably at least 85%, 90%, 95% or with 100% sequence identity, to SEQ ID NO 7:

EVQLVESGGGLVQPGX1SLX2LSCX3ASGFTFSTSGMX4WFRQAPGKGLX5WVX6YISSSS
GFVYADX7VKGRFTISRDNAX8LYLQX9NSLX10X11EDTAX12YYCARSEAAFWGQGTL
VTVSS,

wherein X1-X12 may be any amino acid, preferably X1: G or K, X2: R or K; X3: A or S; X4: N or H; X5: E or D; X6: S or A; X7: S or A; X8: S or T; X9: M or L; X10: R or K, X11: A or S; X12: V or I;

and a VL domain with at least 80% sequence identity, preferably at least 85%, 90%, 95% or with 100% sequence identity, to SEQ ID NO 8:

DIVLTQX1PRSX2PVTPGEX3ASISCRSX4KSRLSRMGITPLNWYLQKPGX5SPQLLIYRMSN
X6ASGVPDRFSGSGSX7TDFTLKISKVETEDVGVYYCAQFLEYPPTFGSGTKLEIK,

wherein X1-X7 may be any amino acid, preferably X1: S or A; X2: L or V; X3: P or S; X4: S or N; X5: Q or K; X6: R or L; X7: G or E.

In preferred embodiments, the sequence variants with 80% or more sequence identity to the specific VH and VL sequences listed herein maintain CXCR5 binding with essentially the same or similar functional properties as VH and VL domains with the specific sequences recited herein, i.e. the CXCR5 binding is essentially the same or similar with respect to affinity, specificity and epitope binding mode.

In one embodiment, the invention relates to a chimeric antigen receptor (CAR) polypeptide as described herein, comprising

- a VH domain according to SEQ ID NO 9

(EVQLVESGGGLVQPGGSLRLSCAASGFTFSTSGMNVWFRQAPGKGLEWVSYISSSSGFVY
ADSVKGRFTISRDNAXNSLYLQMNSLRAEDTAVYYCARSEAAFWGQGTLVTSS),

- or SEQ ID NO 10
(EVQLVESGGGLVQPGKSLKLSASGFTFSTSGMHWFRQAPGKGLDWVAYISSSSGFVY
ADAVKGRFTISRDNANTLYLQLNSLKSEDTAIYYCARSEAAFWGQGTLTVSS)
 - and a VL domain according to SEQ ID NO 11
5 (DIVLTQSPRSLPVTGPGEASISCRSSKSRLSRMGITPLNWYLQKPGQSPQLLIYRMSNRAS
GVPDRFSGSGSGTDFTLKISKVETEDVGVYYCAQFLEYPPTFGSGTKLEIK),
 - or SEQ ID NO 12
(DIVLTQAPRSVSVTPGESASISCRSNKSRLSRMGITPLNWYLQKPGKSPQLLIYRMSNLAS
GVPDRFSGSGSETDFTLKISKVETEDVGVYYCAQFLEYPPTFGSGTKLEIK).
- 10 In further embodiments, the invention relates to a chimeric antigen receptor (CAR) polypeptide that comprises one or more linker, spacer, transmembrane, and signaling domains. In one embodiment, the CAR comprises an intracellular domain, which comprises a co-stimulatory domain and a signalling (activation) domain.
- In one embodiment, the invention relates to a chimeric antigen receptor (CAR) polypeptide as
- 15 described herein, wherein the extracellular antigen-binding domain comprises a linker polypeptide positioned between the VH and VL domains, wherein said linker is preferably selected from
- a Whitlow (SEQ ID NO 13; GSTSGSGKPGSGEGSTKG), or
 - Gly-Ser (SEQ ID NO 14; SSGGGGSGGGGSGGGGS) linker, or
 - linkers with at least 80% sequence identity to SEQ ID NO 13 or 14.
- 20 In one embodiment, the invention relates to a chimeric antigen receptor (CAR) polypeptide as described herein, comprising additionally a spacer polypeptide positioned between the extracellular antigen-binding domain and the transmembrane domain, wherein said spacer is selected from:
- IgG1 spacer (SEQ ID NO 15;
25 PAEPKSPDKTHTCPPCPAPPVAGPSVFLFPPKPKDTLMIARTPEVTCVVVDVSHEDPEVKF
NWYVDGVEVHNAKTKPREEQYNSTYRVVSVLTVLHQDWLNGKEYKCKVSNKALPAPIEKTI
SKAKGQPREPQVYTLPPSRDELTKNQVSLTCLVKGFYPSDIAVEWESNGQPENNYKTTTPPV
LDSDGSFFLYSKLTVDKSRWQQGNVFSCSVMHEALHNHYTQKSLSLSPGKKDPK),
 - IgG1Δ spacer (SEQ ID NO 16;
30 PAEPKSPDKTHTCPPCPAPPVAGPSVFLFPPKPKDTLMIARTPEVTCVVVDVSHEDPEVKF
NWYVDGVEVHNAKTKPREEQYNSTYRVVSVLTVLHQDWLNGKEYKCKVSNKALPAPIEKTI
SKAKGQPREPQVYTLPPSRDELTKNQVSLTCLVKGFYPSDIAVEWESNGQPENNYKTTTPPV
LDSDGSFFLYSKLTVDKSRWQQGNVFSCSVMHEALHNHYTQKSLSLSPGKK),
 - IgG4 (Hi-CH2-CH3) spacer (SEQ ID NO 17;
35 ESKYGPPCPPCPAPEFEGGPSVFLFPPKPKDTLMISRTPEVTCVVVDVSDPEVQFNWY
VDGVEVHNAKTKPREEQFNSTYRVVSVLTVLHQDWLNGKEYKCKVSNKGLPSSIEKTISKA
KGQPREPQVYTLPPSQEEMTKNQVSLTCLVKGFYPSDIAVEWESNGQPENNYKTTTPVLD
SDGSFFLYSRLTVDKSRWQEGNVFSCSVMHEALHNHYTQKSLSLSLGK),
 - IgG4 (Hi-CH3) spacer (SEQ ID NO 18;
40 ESKYGPPCPPCPGQPREPQVYTLPPSQEEMTKNQVSLTCLVKGFYPSDIAVEWESNGQPE
NNYKTTTPVLDSDGSFFLYSRLTVDKSRWQEGNVFSCSVMHEALHNHYTQKSLSLSLGK),
 - IgG4 (Hi) spacer (SEQ ID NO 19; ESKYGPPCPPCP), or
 - a spacer with at least 80% sequence identity to any one of SEQ ID NO 15 to 19.

In one embodiment, the invention relates to a chimeric antigen receptor (CAR) polypeptide as described herein, wherein the transmembrane domain is selected from:

- a CD8 α domain (SEQ ID NO 20; IYIWAPLAGTCGVLLLSLVITLYC), or
- a CD28 domain (SEQ ID NO 21; FWVLVVVGGVLACYSLVTVAFIIFWV), or
- 5 - transmembrane domains with at least 80% sequence identity to SEQ ID NO 20 or 21.

In one embodiment, the invention relates to a chimeric antigen receptor (CAR) polypeptide as described herein, wherein the intracellular domain comprises:

- a co-stimulatory domain selected from a 4-1BB co-stimulatory domain (SEQ ID NO 22; KRGRKKLLYIFKQPFMRPVQTTQEEDGCSCRFPEEEEGGCEL), and/or
- 10 - a CD28 co-stimulatory domain (SEQ ID NO 23; RSKRSRLLHSDYMNMTPRRPGPTRKHYPYAPPRDFAAYRSL), or
- a co-stimulatory domain comprising both a 4-1BB (SEQ ID NO 22) and a CD28 co-stimulatory domain (SEQ ID NO 23) arranged adjacently, or
- a co-stimulatory domain with at least 80% sequence identity to SEQ ID NO 22 or 23.

15 In one embodiment, the invention relates to a chimeric antigen receptor (CAR) polypeptide as described herein, comprising additionally a signaling domain (otherwise known as an activation domain), wherein said signaling domain is

- a CD3zeta (4-1BB or CD28) signaling domain (SEQ ID NO 24; LRVKFSRSADAPAYQQGQNQLYNELNLGRREEYDVLDKRRGRDPEMGGKPRRKNPQEGLYNELQKDKMAEAYSEIGMKGERRRGKGHDGLYQGLSTATKDTYDALHMQALPPR), or
- 20 - a signaling domain with at least 80% sequence identity to SEQ ID NO 24.

In one embodiment, the invention relates to a chimeric antigen receptor (CAR) polypeptide as described herein, comprising a sequence according to any one of SEQ ID NO 25, 26, 27, 28 or 29.

25 The exchange of signaling domains meets the demands for either a strong and rapid effector phase (CD28 co-stimulatory domain), or a long-lasting relapse control as secured by a T cell memory population (4-1BB signaling domain). As demonstrated herein, the various signaling domains may be exchanged in multiple configuration, providing a CAR with flexibility with respect to its design without loss of the advantageous binding properties.

In further embodiments of the invention, the CAR may comprise the following configurations:

- 30 - H28: MP71-hCXCR5-VH-Whitlow-VL-IgG1-CD28-CD28-CD3z
- R28: MP71-ratCXCR5-VH-Whitlow-VL-IgG1-CD28-CD28-CD3z
- HBB1: MP71-hCXCR5-VH-Whitlow-VL-IgG1 Δ -CD8 α -4-1BB-CD3z
- HBB2: MP71-hCXCR5-VH-Whitlow-VL-IgG1-CD28-4-1BB-CD3z
- H28BB: MP71-hCXCR5-VH-Whitlow-VL-IgG1-CD28-CD28-4-1BB-CD3z

35 The particular configurations are intended as preferred but non-limiting embodiments. The configurations above are also not intended to be limited by the specific sequences of those embodiments described herein. Sequence variation, in the context of these configurations, is possible and is encompassed by the scope of the present invention.

40 Due to the variants (by adding alternative components) employed as the linker, spacer, transmembrane and intracellular domains, it becomes apparent that the various components may be

exchanged at required by the skilled person, and the CXCR5 binding properties may be maintained, thereby maintaining the desired biological effects.

In preferred embodiments, in combination with the MP71-vector and a gamma-retrovirus expression system, an unusually high transduction rate for human T cells can be achieved. The transduction system is variable due to a modular design of the CAR construct, meaning that lentiviruses as well as transposons can be employed, depending on the needs and preferences of the skilled person when carrying out the invention. Transfer of the genetic information/nucleic acid molecule for the CXCR5 CAR also includes CrispR/Cas and TALEN mediated insertion into target cell lines, preferably T lymphocytes, Natural Killer Cells, and induced pluripotent stem cells, iPS. All suitable methods for transferring the genetic information/nucleic acid molecule for the CXCR5 CAR into the cell expressing said CAR are encompassed by the present invention, and a suitable method may be selected by a skilled person when carrying out the invention. For example, multiple methods of transforming T cells are known in the art, including any given viral-based gene transfer method, such as those based on modified Retroviridae, and non-viral methods such as DNA-based transposons and direct transfer of mRNA by electroporation.

Additionally, the signaling components of the CAR construct have been exchanged in a three step cloning procedure that allows for a modular composition, and tailor-made construction by a skilled person, of clinically applicable anti-CXCR5 CARs.

In a further aspect of the invention, the invention relates to an isolated nucleic acid molecule, preferably in the form of a vector, such as a viral vector or a transposon vector, preferably a sleeping beauty vector, selected from the group consisting of:

a) a nucleic acid molecule comprising a nucleotide sequence

- which encodes a chimeric antigen receptor (CAR) polypeptide according to any embodiment of the CAR described herein,
- which encodes an extracellular antigen-binding domain, a transmembrane domain, and an intracellular domain, wherein the extracellular antigen-binding domain is encoded by at least one sequence of SEQ ID NO 37 or 38, and at least one sequence of SEQ ID NO 39 or 40,
- according to SEQ ID No. 31, 32, 33, 34, or 35, and/or

b) a nucleic acid molecule which is complementary to a nucleotide sequence in accordance with a);

c) a nucleic acid molecule comprising a nucleotide sequence having sufficient sequence identity to be functionally analogous/equivalent to a nucleotide sequence according to a) or b), comprising preferably a sequence identity to a nucleotide sequence according to a) or b) of at least 80%;

d) a nucleic acid molecule which, as a consequence of the genetic code, is degenerate to a nucleotide sequence according to a) through c); and/or

e) a nucleic acid molecule according to a nucleotide sequence of a) through d) which is modified by deletions, additions, substitutions, translocations, inversions and/or insertions and is functionally analogous/equivalent to a nucleotide sequence according to a) through d).

In preferred embodiments of the invention, the isolated nucleic acid molecule, preferably in the form of a vector, such as a viral vector or a transposon vector, preferably a sleeping beauty vector, is selected from the group consisting of:

- a) a nucleic acid molecule comprising a nucleotide sequence
 - 5 - which encodes a chimeric antigen receptor (CAR) polypeptide according to any embodiment of the CAR described herein,
 - 10 - which encodes an extracellular antigen-binding domain, a transmembrane domain, and an intracellular domain, wherein the extracellular antigen-binding domain is encoded by at least one sequence of SEQ ID NO 37, 53 or 38, and at least one sequence of SEQ ID NO 39, 54 or 40,
 - 15 - according to SEQ ID No. 31, 32, 33, 34, or 35, and/or
 - b) a nucleic acid molecule which is complementary to a nucleotide sequence in accordance with a);
 - c) a nucleic acid molecule comprising a nucleotide sequence having sufficient sequence
 - 20 identity to be functionally analogous/equivalent to a nucleotide sequence according to a) or b), comprising a sequence identity to a nucleotide sequence according to a) or b) of at least 80%, preferably 90%, or 95% sequence identity to a nucleotide sequence according to a) or b), wherein functional analogy relates to binding CXCR5 target antigen, and when corresponding T cells express said construct, the CAR-T cell product confers T cells with a cytotoxic activity against mature B-NHLs, while sparing normal hematopoietic cells such as T cells (except for Tfh or other T cell lymphomas described herein), plasma B cells and their bone marrow precursors; and/or
 - 25 d) a nucleic acid molecule which, as a consequence of the genetic code, is degenerate to a nucleotide sequence according to a) through c).
- The term degenerate to (or degenerated into) refers to differences in nucleotide sequence of a nucleic acid molecule, but according to the genetic code, do not lead to differences in amino acid protein product of the nucleotide sequence after translation. In one embodiment, the nucleic acid molecule relates to the above molecules under a) and b), a), b) and c), or a), b) and d).

Preferred amino acid and nucleotide sequences of the present invention:

SEQ ID No.	Sequence	Description
1	GFTFSTSG	H-CDR1
2	ISSSSGFV	H-CDR2
3	ARSEAAF	H-CDR3
4	KSRLSRMGITP	L-CDR1
5	RMS	L-CDR2
6	AQFLEYPPT	L-CDR3
7	EVQLVESGGGLVQPGX1SLX2LSCX3ASGFTFSTSGMX4WFRQAPGKGLX5WVX6YISSSSGFVYADX7VKGRFTISRDNAX8LYLQX9NSLX10X11EDTAX12YYCARSEAAFWGQGTLTVSS	VH sequence "generalized" encompassing both rat and humanized sequences

	wherein X1: G OR K, X2: R OR K; X3: A OR S; X4: N OR H; X5: E OR D; X6: S OR A; X7: S OR A; X8: S OR T; X9: M OR L; X10: R OR K, X11: A OR S; X12: V OR I	
7	EVQLVESGGGLVQPGXSLXLSCXASGFTFSTSGMXWFRQAPGKGLX WVXYISSSSGFVYADSVKGRFTISRDNALYNLYLQXNSLXXEDTAXYY CARSEAAFWGQGTLVTVSS wherein X is any amino acid, preferably those above.	VH sequence “generalized” encompassing both rat and humanized sequences
8	DIVLTQX ¹ PRSX ² PVTPGEX ³ ASISCRSX ⁴ KSRLSRMGITPLNWYLQKP GX ⁵ SPQLLIYRMSNX ⁶ ASGVDPDRFSGSGSX ⁷ TDFTLKISKVETEDVGVY YCAQFLEYPPTFGSGTKLEIK wherein X1: S or A; X2: L or V; X3: P or S; X4: S or N; X5: Q or K; X6: R or L; X7: G or E	VL sequence “generalized” encompassing both rat and humanized sequences
8	DIVLTQXPRSX ¹ PVTPGEXASISCRSX ² KSRLSRMGITPLNWYLQKPGXS PQLLIYRMSNXASGVDPDRFSGSGSXTDFTLKISKVETEDVGVYYCAQF LEYPPTFGSGTKLEIK wherein X is any amino acid, preferably those above.	VL sequence “generalized” encompassing both rat and humanized sequences
9	EVQLVESGGGLVQPGGSLRLSCAASGFTFSTSGMWNWFRQAPGKGLE WVSYYISSSSGFVYADSVKGRFTISRDNALYNLYLQMNSLRAEDTAVYY CARSEAAFWGQGTLVTVSS	Humanized VH
10	EVQLVESGGGLVQPGKSLKLSCASGFTFSTSGMHWFRQAPGKGLD WVAYISSSSGFVYADAVKGRFTISRDNALYNLYLQLNSLKSIEDTAIYYC ARSEAAFWGQGTLVTVSS	Rat VH
11	DIVLTQSPRSLPVTTPGEPASISCRSSK ¹ SRLSRMGITPLNWYLQKPGQS PQLLIYRMSNRRASGVDPDRFSGSGSGTDFTLKISKVETEDVGVYYCAQF LEYPPTFGSGTKLEIK	Humanized VL
12	DIVLTQAPRSVSVTPGESASISCRSNK ¹ SRLSRMGITPLNWYLQKPGKS PQLLIYRMSNRRASGVDPDRFSGSGSGTDFTLKISKVETEDVGVYYCAQF LEYPPTFGSGTKLEIK	Rat VL
13	GSTSGSGKPGSGEGSTKG	Whitlow linker
14	SSGGGGSGGGGGSGGGGS	Gly-Ser linker
15	PAEPKSPDKTHTCPPCPAPPVAGPSVFLFPPKPKDTLMIARTPEVTCV VVDVSHEDPEVKFNWYVDGVEVHNAKTKPREEQYNSTYRVVSVLTVL HQDWLNGKEYKCKVSNKALPAPIEKTISKAKGQPREPQVYTLPPSRDE LTKNQVSLTCLVKGFYPSDIAVEWESNGQPENNYKTTTPVLDSDGSFF LYSKLTVDKSRWQQGNVFSCSVMHEALHNHYTQKSLSLSPGKKDPK	IgG1 spacer
16	PAEPKSPDKTHTCPPCPAPPVAGPSVFLFPPKPKDTLMIARTPEVTCV VVDVSHEDPEVKFNWYVDGVEVHNAKTKPREEQYNSTYRVVSVLTVL HQDWLNGKEYKCKVSNKALPAPIEKTISKAKGQPREPQVYTLPPSRDE LTKNQVSLTCLVKGFYPSDIAVEWESNGQPENNYKTTTPVLDSDGSFF LYSKLTVDKSRWQQGNVFSCSVMHEALHNHYTQKSLSLSPGKK	IgG1Δ spacer
17	ESKYGPPCPPCPAPEFEGGPSVFLFPPKPKDTLMISRTPEVTCVVVDV SQEDPEVQFNWYVDGVEVHNAKTKPREEQFNSTYRVVSVLTVLHQD WLNGKEYKCKVSNKGLPSSIEKTISKAKGQPREPQVYTLPPSQEEMTK NQVSLTCLVKGFYPSDIAVEWESNGQPENNYKTTTPVLDSDGSFFLYS RLTVDKSRWQEGNVFSCSVMHEALHNHYTQKSLSLSPGK	IgG4 (HI-CH2- CH3) spacer
18	ESKYGPPCPPCPGQPREPQVYTLPPSQEEMTKNQVSLTCLVKGFYPS DIAVEWESNGQPENNYKTTTPVLDSDGSFFLYSRLTVDKSRWQEGNV FSCSVMHEALHNHYTQKSLSLSPGK	IgG4 (HI-CH3) spacer
19	ESKYGPPCPPCP	IgG4 (HI) spacer

20	IYIWAPLAGTCGVLLLSLVITLYC	transmembran e domain CD8α
21	FWVLVVGGVLACYSLLVTVAFIIFWV	transmembran e domain CD28
22	KRGRKKLLYIFKQPFMRPVQTTQEEDGCSCRFPEEEEEGGCEL	Co-stimulatory domain 4-1BB
23	RSKRSRLLHSDYMNMTPRRPGPTRKHYPYAPPRDFAAYRSL	Co-stimulatory domain CD28
24	LRVKFSRSADAPAYQQGQNQLYNELNLGRREEYDVLDKRRGRDPEM GGKPRRKNPQEGLYNELQKDKMAEAYSEIGMKGERRRGKGHDGLYQ GLSTATKDTYDALHMQALPPR	Activation domain CD3 zeta (4- 1BB) or (CD28)
25	MDFQVQIFSFLNISASVIMSREVQLVESGGGLVQPGGSLRLSCAASGF TFSTSGMWNFRQAPGKGLEWVSYISSSSGFVYADSVKGRFTISRDN QNSLYLQMNSLRAEDTAVYYCARSEAAFWGQGTLLTVSSGSTSGSG KPGSGEGSTKGDIVLTQSPRSLPVTGPGEPAISCRSSKSRLSRMGITPL NWYLQKPGQSPQQLLIYRMSNRASGVPDRFSGSGSGTDFTLKISKVETE DVGVEYYCAQFLEYPPTFGSGTKLEIKPAEPKSPDKTHTCPPCPAPPVA GPSVFLFPPKPKDTLMIARTPEVTCVVVDVSHEDPEVKFNWYVDGVEV HNAKTKPREEQYNSTYRVVSVLTVLHQDWLNGKEYKCKVSNKALPAPI EKTISKAKGQPREPQVYTLPPSRDELTKNQVSLTCLVKGFYPSDIAVE WESNGQPENNYKTTTPVLDSDGSFFLYSKLTVDKSRWQQGNVFCSS VMHEALHNHYTQKSLSLSPGKKDPKFWVLVVVGGVLACYSLLVTVAFII FWVRSKRSRLLHSDYMNMTPRRPGPTRKHYPYAPPRDFAAYRSLR VKFSRSADAPAYQQGQNQLYNELNLGRREEYDVLDKRRGRDPEMGG KPRRKNPQEGLYNELQKDKMAEAYSEIGMKGERRRGKGHDGLYQGL STATKDTYDALHMQALPPR	H28 MP71- hCXCR5-VH- Whitlow-VL- IgG1-CD28- CD28-CD3z
26	MDFQVQIFSFLNISASVIMSREVQLVESGGGLVQPGKSLKLSCSASGFT FSTSGMHWFRQAPGKGLDWVAYISSSSGFVYADAVKGRFTISRDN NTLYLQLNSLKSEDTAIYYCARSEAAFWGQGTLLTVSSGSTSGSGKPG SGEGSTKGDIVLTQAPRSVSVTPGESASISCRSNKSRLSRMGITPLNW YLQKPGKSPQQLLIYRMSNLASGVPDRFSGSGSETDFTLKISKVETEDV GVYYCAQFLEYPPTFGSGTKLEIKPAEPKSPDKTHTCPPCPAPPVAGP SVFLFPPKPKDTLMIARTPEVTCVVVDVSHEDPEVKFNWYVDGVEVHN AKTKPREEQYNSTYRVVSVLTVLHQDWLNGKEYKCKVSNKALPAPIEK TISKAKGQPREPQVYTLPPSRDELTKNQVSLTCLVKGFYPSDIAVEWE SNGQPENNYKTTTPVLDSDGSFFLYSKLTVDKSRWQQGNVFCSSVM HEALHNHYTQKSLSLSPGKKDPKFWVLVVVGGVLACYSLLVTVAFIIFW VRSKRSRLLHSDYMNMTPRRPGPTRKHYPYAPPRDFAAYRSLRVKF SRSADAPAYQQGQNQLYNELNLGRREEYDVLDKRRGRDPEMGGKPR RKNPQEGLYNELQKDKMAEAYSEIGMKGERRRGKGHDGLYQGLSTA TKDTYDALHMQALPPR	R28 MP71- ratCXCR5-VH- Whitlow-VL- IgG1-CD28- CD28-CD3z
27	MDFQVQIFSFLNISASVIMSREVQLVESGGGLVQPGGSLRLSCAASGF TFSTSGMWNFRQAPGKGLEWVSYISSSSGFVYADSVKGRFTISRDN QNSLYLQMNSLRAEDTAVYYCARSEAAFWGQGTLLTVSSGSTSGSG KPGSGEGSTKGDIVLTQSPRSLPVTGPGEPAISCRSSKSRLSRMGITPL NWYLQKPGQSPQQLLIYRMSNRASGVPDRFSGSGSGTDFTLKISKVETE DVGVEYYCAQFLEYPPTFGSGTKLEIKPAEPKSPDKTHTCPPCPAPPVA GPSVFLFPPKPKDTLMIARTPEVTCVVVDVSHEDPEVKFNWYVDGVEV HNAKTKPREEQYNSTYRVVSVLTVLHQDWLNGKEYKCKVSNKALPAPI EKTISKAKGQPREPQVYTLPPSRDELTKNQVSLTCLVKGFYPSDIAVE WESNGQPENNYKTTTPVLDSDGSFFLYSKLTVDKSRWQQGNVFCSS VMHEALHNHYTQKSLSLSPGKKIYIWAPLAGTCGVLLLSLVITLYCKR	HBB1 MP71- hCXCR5-VH- Whitlow-VL- IgG1Δ-CD8α- 4-1BB-CD3z

	GRKKLLYIFKQPFMRPVQTTQEEDGCSCRFPEEEEEGGCELLRVKFSR SADAPAYQQGQNQLYNELNLGRREEYDVLDKRRGRDPEMGGKPRRK NPQEGLYNELQKDKMAEAYSEIGMKGERRRRGKGHDGLYQGLSTATK DTYDALHMQALPPR	
28	MDFQVQIFSLLISASVIMSREVQLVESGGGLVQPGGSLRLSCAASGF TFSTSGMNWFRQAPGKGLEWVSYISSSSGFVYADSVKGRFTISRDN QNSLYLQMNSLRAEDTAVYYCARSEAAFWGQGT LVT VSSGSTSGSG KPGSGEGSTKGDIVLTQSPRSLPVTGPASISCRSSKSRLSRMGITPL NWYLQKPGQSPQLLIYRMSNRASGVPDRFSGSGSGTDFTLKISKVETE DVG VYYCAQFLEYPPTFGSGTKLEIKPAEPKSPDKTHTCPPCPAPPVA GPSVFLFPPKPKDTLMIARTPEVTCVVVDVSHEDPEVKFNWYVDGVEV HNAKTKPREEQYNSTYRVVSVLTVLHQDWLNGKEYKCKVSNKALPAPI EKTISKAKGQPREPQVYTLPPSRDELTKNQVSLTCLVKGFYPSDIAVE WESNGQPENNYKTTTPVLDSDGSFFLYSKLTVDKSRWQQGNVFCSS VMHEALHNHYTQKSLSLSPGKKDPKFWVLVVVGGLVACYSLLVTVAFII FWVKRGRKKLLYIFKQPFMRPVQTTQEEDGCSCRFPEEEEEGGCELLR VKFSRSADAPAYQQGQNQLYNELNLGRREEYDVLDKRRGRDPEMGG KPRRKNPQEGLYNELQKDKMAEAYSEIGMKGERRRRGKGHDGLYQGL STATKDTYDALHMQALPPR	HBB2 MP71- hCXCR5-VH- Whitlow-VL- IgG1-CD28-4- 1BB-CD3z
29	MDFQVQIFSLLISASVIMSREVQLVESGGGLVQPGGSLRLSCAASGF TFSTSGMNWFRQAPGKGLEWVSYISSSSGFVYADSVKGRFTISRDN QNSLYLQMNSLRAEDTAVYYCARSEAAFWGQGT LVT VSSGSTSGSG KPGSGEGSTKGDIVLTQSPRSLPVTGPASISCRSSKSRLSRMGITPL NWYLQKPGQSPQLLIYRMSNRASGVPDRFSGSGSGTDFTLKISKVETE DVG VYYCAQFLEYPPTFGSGTKLEIKPAEPKSPDKTHTCPPCPAPPVA GPSVFLFPPKPKDTLMIARTPEVTCVVVDVSHEDPEVKFNWYVDGVEV HNAKTKPREEQYNSTYRVVSVLTVLHQDWLNGKEYKCKVSNKALPAPI EKTISKAKGQPREPQVYTLPPSRDELTKNQVSLTCLVKGFYPSDIAVE WESNGQPENNYKTTTPVLDSDGSFFLYSKLTVDKSRWQQGNVFCSS VMHEALHNHYTQKSLSLSPGKKDPKFWVLVVVGGLVACYSLLVTVAFII FWVRSKRSRLLHSDYMNMTPRRPGPTRKHYPYAPPRDFAAYRSLK RGRKKLLYIFKQPFMRPVQTTQEEDGCSCRFPEEEEEGGCEL RVKFSR SADAPAYQQGQNQLYNELNLGRREEYDVLDKRRGRDPEMGGKPRRK NPQEGLYNELQKDKMAEAYSEIGMKGERRRRGKGHDGLYQGLSTATK DTYDALHMQALPPR	H28BB MP71- hCXCR5-VH- Whitlow-VL- IgG1-CD28- CD28-4-1BB- CD3z
30	MDFQVQIFSLLISASVIMSR	Lkappa Leader
31	ATGGATTTCCAGGTGCAGATCTTCAGCTTCCTGCTGATCTCCGCCA GCGTGATCATGAGCCGCGAGGTGCAGCTGGTGGAATCTGGCGGA GGA CTGGTGCAGCCTGGCGGCTCTCTGAGACTGTCTTGTGCCGCC AGCGGCTTCACCTTCAGCACCGAGCGGCATGAACTGGTTCAGACAG GCCCCCTGGCAAGGGCCTGGAATGGGTGTCCTACATCAGCAGCAGC TCCGGCTTCGTGTACGCCGACAGCGTGAAGGGCCGGTTCACCATC AGCAGAGACAACGCCCAGAACAGCCTGTACCTGCAGATGAACTCC CTGCGGGCCGAGGACACCGCCGTGTACTACTGTGCCAGAAGCGAG GCCGCCTTTTGGGGCCAGGGAACACTCGTGACAGTGTCCAGCGGC AGCACAAGCGGCTCTGGCAAACCTGGATCTGGCGAGGGGCAGCACC AAGGGCGATATCGTGCTGACCCAGAGCCCCAGATCCCTGCCTGTG ACACCTGGCGAGCCTGCCAGCATCAGCTGCAGAAGCAGCAAGAGC CGGCTGAGCCGGATGGGCATCACCCCCCTGAACTGGTATCTGCAG AAACCCGGCCAGTCCCCCAGCTGCTGATCTACCGGATGAGCAAC AGAGCCAGCGGCGTGCCCGATAGATTTTCCGGCTCTGGAAGCGGC ACCGACTTCACCCTGAAGATCAGCAAGGTGGAAACCGAGGACGTG GGCGTGTACTATTGCGCCCCAGTTCCTGGAATACCCCCCACCTTTG GCAGCGGCACCAAGCTGGAATCAAGCCCGCCGAGCCCAAGAGC CCCGACAAGACCCATACCTGCCCTCCATGTCCTGCCCTCCAGTG GCTGGCCCTAGCGTGTTCTGTTCCCCCAAAGCCCAAGGACACC CTGATGATCGCCCGGACCCCTGAAGTGACCTGCGTGGTGGTGGAT GTGTCCACGAGGATCCCGAAGTGAAGTTCAATTGGTACGTGGAC	H28 MP71- hCXCR5-VH- Whitlow-VL- IgG1-CD28- CD28-CD3z

	GGCGTGGAAGTGCACAACGCCAAGACCAAGCCCAGAGAGGAACAG TACAACAGCACCTACCGGGTGGTGTCTGTGCTGACCGTGCTGCAT CAGGACTGGCTGAACGGCAAAGAGTACAAGTGCAAGGTGTCCAAC AAGGCCCTGCCTGCCCCCATCGAGAAAACCATCTCCAAGGCCAAG GGACAGCCCCGCGAGCCCCAGGTGTACACACTGCCTCCAAGCAGG GACGAGCTGACCAAGAACCAGGTCAGCCTGACCTGCCTGGTCAA GGCTTCTATCCCAGCGACATCGCCGTGGAGTGGGAGAGCAATGGG CAGCCGGAGAACAACACTACAAGACCACGCCTCCCGTGCTGGACTCC GACGGCTCCTTCTTCTCTACAGCAAGCTCACCGTGGACAAGAGCA GGTGGCAGCAGGGGAACGTCTTCTCATGCTCCGTGATGCATGAGG CTCTGCACAACCACTACACGCAGAAGAGCCTCTCCCTGTCTCCGG GTAAAAAAGATCCCAAATTTTGGGTGCTGGTGGTGGTTGGTGGAGT CCTGGCTTGCTATAGCTTGCTAGTAACAGTGGCCTTTATTATTTCT GGGTGAGGAGTAAGAGGAGCAGGCTCCTGCACAGTGA CTACATGA ACATGACTCCCCGCGCGCCCCGGGCCACCCGCAAGCATTACCAGC CCTATGCCCCACCACGCGACTTCGCAGCCTATCGCTCCCTGAGAG TGAAGTTCAGCAGGAGCGCAGACGCCCCCGCGTACCAGCAGGGC CAGAACCAGCTCTATAACGAGCTCAATCTAGGACGAAGAGAGGAGT ACGATGTTTTGGACAAGAGACGTGGCCGGGACCCTGAGATGGGGG GAAAGCCGAGAAGGAAGAACCCTCAGGAAGGCCTGTACAATGAAC TGCAGAAAGATAAGATGGCGGAGGCCTACAGTGAGATTGGGATGA AAGGCGAGCGCCGGAGGGGCAAGGGGCACGATGGCCTTTACCAG GGTCTCAGTACAGCCACCAAGGACACCTACGACGCCCTTCACATG CAGGCCCTGCCCCCTCGCTGA	
32	ATGGATTTCCAGGTGCAGATCTTCAGCTTCCTGCTGATCTCCGCCA GCGTGATCATGAGCCGCGAGGTACAGCTGGTGGAGTCTGGAGGAG GCTTAGTGACGCTGGAAAGTCCCTGAAACTCTCCTGTTACGCCTC TGGATTCACATTCAGTACCTCTGGCATGCACTGGTTTCGCCAAGCT CCAGGAAAGGGGCTGGATTGGGTTCATACATTAGTAGTAGCAGC GGTTTCGTCTATGCAGACGCTGTGAAGGGCCGGTTCACCATCTCCA GAGACAATGCACAGAACACCCTGTACCTGCAACTCAACAGTCTGAA GTCTGAAGACACTGCCATCTATTACTGTGCAAGAAGCGAGGCTGCT TTCTGGGGCCAAGGCACTCTGGTCACTGTCTCTTCAGGCAGCACCA GCGGCTCCGGCAAGCCTGGCTCTGGCGAGGGCAGCACAAAGGGA GATATTGTGTTGACTCAAGCTCCACGCTCTGTATCTGTCACTCCTG GAGAGTCAGCTTCCATCTCCTGCAGGTCTAATAAGAGTCGACTGAG TAGGATGGGCATCACTCCCTTGAATTGGTACCTTCAGAAGCCAGGA AAGTCTCCTCAGCTCCTGATATATCGGATGTCCAACCTTGCCTCAG GAGTTCCAGACAGGTTTAGTGGCAGTGGGTGAGAAACAGATTTTAC ACTGAAAATCAGTAAGGTGGAGACTGAGGATGTTGGCGTTTATTAC TGTGCACAGTTTCTAGAATATCCTCCTACGTTCCGGTTCTGGGACCA AGCTGGAGATCAAACCTGCCGAGCCTAAGAGCCCCGACAAGACCC ACACCTGTCCCCCTTGTCTGCCCCCTCCAGTGGCTGGCCCTAGCG TGTTCTGTTCCTCCCCCAAAGCCCAAGGATACCCTGATGATCGCCCG GACCCCCGAAGTCACATGCGTGGTGGTGGACGTGAGCCACGAAGA CCCTGAGGTCAAGTTCAACTGGTACGTGGACGGCGTGGAGGTGCA TAATGCCAAGACAAAGCCGCGGGAGGAGCAGTACAACAGCACGTA CCGTGTGGTCAGCGTCCTCACCGTCCTGCACCAGGACTGGCTGAA TGGCAAGGAGTACAAGTGCAAGGTCTCCAACAAAGCCCTCCCAGC CCCCATCGAGAAAACCATCTCCAAGCCAAAGGGCAGCCCCGAGA ACCACAGGTGTACACCCTGCCCCCATCCCGGGATGAGCTGACCAA GAACCAGGTCAGCCTGACCTGCCTGGTCAAAGGCTTCTATCCCAG CGACATCGCCGTGGAGTGGGAGAGCAATGGGCAGCCGGAGAACA ACTACAAGACCACGCCTCCCGTGCTGGACTCCGACGGCTCCTTCTT CCTCTACAGCAAGCTCACCGTGGACAAGAGCAGGTGGCAGCAGGG GAACGTCTTCTCATGCTCCGTGATGCATGAGGCTCTGCACAACCAC TACACGCAGAAGAGCCTCTCCCTGTCTCCGGGTAAAAAAGATCCCA AATTTTGGGTGCTGGTGGTGGTTGGTGGAGTCCTGGCTTGCTATAG CTTGCTAGTAACAGTGGCCTTTATTATTTTCTGGGTGAGGAGTAAGA GGAGCAGGCTCCTGCACAGTGA CTACATGAACATGACTCCCCGCC GCCCCGGGCCACCCGCAAGCATTACCAGCCCTATGCCCCACCAC	R28 MP71- ratCXCR5-VH- Whitlow-VL- IgG1-CD28- CD28-CD3z

	GCGACTTCGCAGCCTATCGCTCCCTGAGAGTGAAGTTCAGCAGGA GCGCAGACGCCCCCGCGTACCAGCAGGGCCAGAACCAGCTCTATA ACGAGCTCAATCTAGGACGAAGAGAGGAGTACGATGTTTTGGACAA GAGACGTGGCCGGGACCCTGAGATGGGGGGAAAGCCGAGAAGGA AGAACCCTCAGGAAGGCCTGTACAATGAACTGCAGAAAGATAAGAT GGCGGAGGCCTACAGTGAGATTGGGATGAAAGGCGAGCGCCGGA GGGGCAAGGGGCACGATGGCCTTTACCAGGGTCTCAGTACAGCCA CCAAGGACACCTACGACGCCCTTCACATGCAGGCCCTGCCCCCTC GCTGA	
33	ATGGATTTCAGGTGCAGATCTTCAGCTTCCTGCTGATCTCCGCCA GCGTGATCATGAGCCGCGAGGTGCAGCTGGTGGAATCTGGCGGA GGAAGTGGTGCAGCCTGGCGGCTCTCTGAGACTGTCTTGTGCCGCC AGCGGCTTCACCTTCAGCACCAAGCGGCATGAACTGGTTCAGACAG GCCCCCTGGCAAGGGCCTGGAATGGGTGTCCTACATCAGCAGCAGC TCCGGCTTCGTGTACGCCGACAGCGTGAAGGGCCGGTTTACCATC AGCAGAGACAACGCCCAGAACAGCCTGTACCTGCAGATGAACTCC CTGCGGGCCGAGGACACCGCCGTGTACTACTGTGCCAGAAGCGAG GCCGCCTTTTGGGGCCAGGGAACTCGTGACAGTGTCCAGCGGC AGCACAAGCGGCTCTGGCAAACCTGGATCTGGCGAGGGGCAGCACC AAGGGCGATATCGTGCTGACCCAGAGCCCCAGATCCCTGCCTGTG ACACCTGGCGAGCCTGCCAGCATCAGCTGCAGAAGCAGCAAGAGC CGGCTGAGCCGGATGGGCATCACCCCCCTGAACTGGTATCTGCAG AAACCCGGCCAGTCCCCCAGCTGCTGATCTACCGGATGAGCAAC AGAGCCAGCGGCGTGCCCGATAGATTTTCCGGCTCTGGAAGCGGC ACCGACTTCACCCTGAAGATCAGCAAGGTGGAAACCGAGGACGTG GGCGTGTAATTTGCGCCCAAGTTCCTGGAATACCCCCCACCTTTG GCAGCGGCACCAAGCTGGAATCAAGCCCGCCGAGCCCAAGAGC CCCGACAAGACCCATACCTGCCCTCCATGTCCTGCCCTCCAGTG GCTGGCCCTAGCGTGTTCTGTTCCCCCAAAGCCCAAGGACACC CTGATGATCGCCCGGACCCCTGAAGTGACCTGCGTGGTGGTGGAT GTGTCCACGAGGATCCCGAAGTGAAGTTCAATTGGTACGTGGAC GGCGTGGAAGTGCACAACGCCAAGACCAAGCCCAGAGAGGAACAG TACAACAGCACCTACCGGGTGGTGTCTGTGCTGACCGTGCTGCAT CAGGACTGGCTGAACGGCAAAGAGTACAAGTGCAAGGTGTCCAAC AAGGCCCTGCCTGCCCCCATCGAGAAAACCATCTCCAAGGCCAAG GGACAGCCCCGCGAGCCCCAGGTGTACACACTGCCTCCAAGCAGG GACGAGCTGACCAAGAACCAGGTGTCCCTGACCTGCCTCGTGAAG GGCTTCTACCCCTCCGATATCGCCGTGGAATGGGAGAGCAATGGC CAGCCCGAGAACAATAACAAGACACCCCCCTGTGCTGGACAGC GACGGCTCATTCTTCTGTACAGCAAGCTGACAGTGGACAAGAGCC GGTGGCAGCAGGGCAACGTGTTCAAGTGCAGCGTGATGCACGAG GCTCTGCACAACCACTACACCCAGAAGTCCCTGAGCAGCCTGAGC CCAGGCAAGAAGATCTACATCTGGGCCCTCTGGCCGGCACCTGT GGCGTGCTGCTGCTGTCTCTCGTGATCACACTGTACTGCAAGCGG GGCAGAAAGAAGCTGCTGTACATCTTCAAGCAGCCCTTCATGCGGC CCGTGCAGACCAACCAGGAAGAGGACGGCTGCTCCTGCAGATTCC CCGAGGAAGAAGAAGGCGGCTGCGAGCTGCTGCGCGTGAAGTTTT CTAGAAGCGCCGACGCCCTGCCTACCAGCAGGGCCAGAACCAGC TGTACAACGAGCTGAACCTGGGCAGACGGGAAGAGTACGACGTGC TGGATAAGCGGAGAGGGCCGGGACCCTGAGATGGGCGGCAAGCCT AGAAGAAAGAACCCCCAGGAAGGCCTGTATAACGAACTGCAGAAA GACAAGATGGCCGAGGCCTACAGCGAGATCGGAATGAAGGGCGA GCGGAGAAGAGGCAAGGGCCACGATGGACTGTACCAGGGCCTGA GCACCGCCACCAAGGACACCTATGACGCCCTGCACATGCAGGCTC TGCCCCCAGATAA	HBB1 MP71- hCXCR5-VH- Whitlow-VL- IgG1Δ-CD8α- 4-1BB-CD3z
34	ATGGATTTCAGGTGCAGATCTTCAGCTTCCTGCTGATCTCCGCCA GCGTGATCATGAGCCGCGAGGTGCAGCTGGTGGAATCTGGCGGA GGAAGTGGTGCAGCCTGGCGGCTCTCTGAGACTGTCTTGTGCCGCC AGCGGCTTCACCTTCAGCACCAAGCGGCATGAACTGGTTCAGACAG GCCCCCTGGCAAGGGCCTGGAATGGGTGTCCTACATCAGCAGCAGC TCCGGCTTCGTGTACGCCGACAGCGTGAAGGGCCGGTTTACCATC	HBB2 MP71- hCXCR5-VH- Whitlow-VL-

	AGCAGAGACAACGCCCAGAACAGCCTGTACCTGCAGATGAACTCC CTGCGGGCCGAGGACACCGCCGTGTACTACTGTGCCAGAAGCGAG GCCGCCTTTTGGGGCCAGGGAACACTCGTGACAGTGTCCAGCGGC AGCACAAGCGGCTCTGGCAAACCTGGATCTGGCGAGGGGCAGCACC AAGGGCGATATCGTGCTGACCCAGAGCCCCAGATCCCTGCCTGTG ACACCTGGCGAGCCTGCCAGCATCAGCTGCAGAAGCAGCAAGAGC CGGCTGAGCCGGATGGGCATCACCCCCCTGAACTGGTATCTGCAG AAACCCGGCCAGTCCCCCAGCTGCTGATCTACCGGATGAGCAAC AGAGCCAGCGGCGTGCCCGATAGATTTTCCGGCTCTGGAAGCGGC ACCGACTTCACCCTGAAGATCAGCAAGGTGGAAACCGAGGACGTG GGCGTGTACTATTGCGCCCAGTTCCTGGAATACCCCCCACCTTTG GCAGCGGCACCAAGCTGGAAATCAAGCCCGCCGAGCCCAAGAGC CCCGACAAGACCCATACCTGCCCTCCATGTCCTGCCCCTCCAGTG GCTGGCCCTAGCGTGTTCTGTTCCCCCAAAGCCCAAGGACACC CTGATGATCGCCCGGACCCCTGAAGTGACCTGCGTGGTGGTGGAT GTGTCCCACGAGGATCCCGAAGTGAAGTTCAATTGGTACGTGGAC GGCGTGGAAGTGACAAACGCCAAGACCAAGCCCAGAGAGGAACAG TACAACAGCACCTACCGGGTGGTGTCTGTGCTGACCGTGCTGCAT CAGGACTGGCTGAACGGCAAAGAGTACAAGTGCAAGGTGTCCAAC AAGGCCCTGCCTGCCCCCATCGAGAAAACCATCTCCAAGGCCAAG GGACAGCCCCGCGAGCCCCAGGTGTACACACTGCCTCCAAGCAGG GACGAGCTGACCAAGAACCAGGTGACCTGACCTGCCTGGTCAAA GGCTTCTATCCCAGCGACATCGCCGTGGAGTGGGAGAGCAATGGG CAGCCGGAGAACAATAAGACACGCCTCCCGTGCTGGACTCC GACGGCTCCTTCTTCTCTACAGCAAGCTCACCGTGGACAAGAGCA GGTGGCAGCAGGGGAACGTCTTCTCATGCTCCGTGATGCATGAGG CTCTGCACAACCACTACACGCAGAAGAGCCTCTCCCTGTCTCCGG GTAAAAAAGATCCCAAATTTTGGGTGCTGGTGGTGGTTGGTGGAGT CCTGGCTTGCTATAGCTTGCTAGTAACAGTGGCCTTTATTATTTTCT GGGTGAAGCGGGGCAGAAAGAAGCTGCTGTACATCTTCAAGCAGC CCTTCATGCGGCCCGTGACAGACCACCCAGGAAGAGGACGGCTGCT CCTGCAGATTCCCCGAGGAAGAAGAAGGCGGCTGCGAGCTGCTGA GAGTGAAGTTCAGCAGGAGCGCAGACGCCCCCGCGTACCAGCAG GGCCAGAACCAGCTCTATAACGAGCTCAATCTAGGACGAAGAGAG GAGTACGATGTTTTGGACAAGAGACGTGGCCGGGACCCTGAGATG GGGGGAAAGCCGAGAAGGAAGAACCCTCAGGAAGGCCTGTACAAT GAACTGCAGAAAGATAAGATGGCGGAGGCCTACAGTGAGATTGGG ATGAAAGGCGAGCGCCGGAGGGGGCAAGGGGCACGATGGCCTTTA CCAGGGTCTCAGTACAGCCACCAAGGACACCTACGACGCCCTTCA CATGCAGGCCCTGCCCCCTCGCTGA	IgG1-CD28-4- 1BB-CD3z
35	ATGGATTTCCAGGTGCAGATCTTCAGCTTCCTGCTGATCTCCGCCA GCGTGATCATGAGCCGCGAGGTGCAGCTGGTGGAAATCTGGCGGA GGAAGTGGTGCAGCCTGGCGGCTCTCTGAGACTGTCTTGCGCGCC AGCGGCTTCACCTTCAGCACCGAGCGGCATGAACTGGTTCAGACAG GCCCTGGCAAGGGCCTGGAATGGGTGTCTACATCAGCAGCAGC TCCGGCTTCGTGTACGCCGACAGCGTGAAGGGCCGGTTACCATC AGCAGAGACAACGCCCAGAACAGCCTGTACCTGCAGATGAACTCC CTGCGGGCCGAGGACACCGCCGTGTACTACTGTGCCAGAAGCGAG GCCGCCTTTTGGGGCCAGGGAACACTCGTGACAGTGTCCAGCGGC AGCACAAGCGGCTCTGGCAAACCTGGATCTGGCGAGGGGCAGCACC AAGGGCGATATCGTGCTGACCCAGAGCCCCAGATCCCTGCCTGTG ACACCTGGCGAGCCTGCCAGCATCAGCTGCAGAAGCAGCAAGAGC CGGCTGAGCCGGATGGGCATCACCCCCCTGAACTGGTATCTGCAG AAACCCGGCCAGTCCCCCAGCTGCTGATCTACCGGATGAGCAAC AGAGCCAGCGGCGTGCCCGATAGATTTTCCGGCTCTGGAAGCGGC ACCGACTTCACCCTGAAGATCAGCAAGGTGGAAACCGAGGACGTG GGCGTGTACTATTGCGCCCAGTTCCTGGAATACCCCCCACCTTTG GCAGCGGCACCAAGCTGGAAATCAAGCCCGCCGAGCCCAAGAGC CCCGACAAGACCCATACCTGCCCTCCATGTCCTGCCCCTCCAGTG GCTGGCCCTAGCGTGTTCTGTTCCCCCAAAGCCCAAGGACACC CTGATGATCGCCCGGACCCCTGAAGTGACCTGCGTGGTGGTGGAT	H28BB MP71- hCXCR5-VH- Whitlow-VL- IgG1-CD28- CD28-4-1BB- CD3z

	GTGTCCCACGAGGATCCCGAAGTGAAGTTCAATTGGTACGTGGAC GGCGTGGAAGTGCACAACGCCAAGACCAAGCCCAGAGAGGAACAG TACAACAGCACCTACCGGGTGGTGTCTGTGCTGACCGTGCTGCAT CAGGACTGGCTGAACGGCAAAGAGTACAAGTGCAAGGTGTCCAAC AAGGCCCTGCCTGCCCCCATCGAGAAAACCATCTCCAAGGCCAAG GGACAGCCCCGCGAGCCCCAGGTGTACACACTGCCTCCAAGCAGG GACGAGCTGACCAAGAACCAGGTCAGCCTGACCTGCCTGGTCAAA GGCTTCTATCCCAGCGACATCGCCGTGGAGTGGGAGAGCAATGGG CAGCCGGAGAACAATAACAAGACCACGCCTCCCGTGCTGGACTCC GACGGCTCCTTCTTCTCTACAGCAAGCTCACCGTGGACAAGAGCA GGTGGCAGCAGGGGAACGTCTTCTCATGCTCCGTGATGCATGAGG CTCTGCACAACCACTACACGCAGAAGAGCCTCTCCCTGTCTCCGG GTAAAAAAGATCCCAAATTTTGGGTGCTGGTGGTGGTTGGTGGAGT CCTGGCTTGCTATAGCTTGCTAGTAACAGTGGCCTTTATTATTTTCT GGGTGAGGAGTAAGAGGAGCAGGCTCCTGCACAGTGA CTACATGA ACATGACTCCCCGCCGCCCGGGCCCCACCCGCAAGCATTACCAGC CCTATGCCCCACCACGCGACTTCGACGCCTATCGCTCCCTGAAGC GGGGCAGAAAGAAGCTGCTGTACATCTTCAAGCAGCCCTTCATGC GGCCCGTGACAGACCACCCAGGAAGAGGACGGCTGCTCCTGCAGAT TCCCCGAGGAAGAAGAAGGCGGCTGCGAGCTGAGAGTGAAGTTCA GCAGGAGCGCAGACGCCCCCGCGTACCAGCAGGGGCCAGAACCAG CTCTATAACGAGCTCAATCTAGGACGAAGAGAGGAGTACGATGTTT TGGACAAGAGACGTGGCCGGGACCCTGAGATGGGGGGAAAGCCG AGAAGGAAGAACCCTCAGGAAGGCCTGTACAATGAACTGCAGAAA GATAAGATGGCGGAGGCCTACAGTGAGATTGGGATGAAAGGCGAG CGCCGGAGGGGGCAAGGGGGCACGATGGCCTTTACCAGGGTCTCAG TACAGCCACCAAGGACACCTACGACGCCCTTCACATGCAGGCCCT GCCCCCTCGCTGA	
36	ATGGATTTCCAGGTGCAGATCTTCAGCTTCCTGCTGATCTCCGCCA GCGTGATCATGAGCCGC	Lkappa Leader
37	GAGGTGCAGCTGGTGGAATCTGGCGGAGGACTGGTGCAGCCTGG CGGCTCTCTGAGACTGTCTTGCGCCAGCGGCTTCACCTTCAG CACCAGCGGCATGAACTGGTTCAGACAGGCCCTGGCAAGGGCCT GGAATGGGTGTCCTACATCAGCAGCAGCTCCGGCTTCGTGTACGC CGACAGCGTGAAGGGCCGGTTCACCATCAGCAGAGACAACGCCCA GAACAGCCTGTACCTGCAGATGAACTCCCTGCGGGCCGAGGACAC CGCCGTGTACTACTGTGCCAGAAGCGAGGCCGCCTTTTGGGGCCA GGGAACACTCGTGACAGTGTCCAGC	Humanized VH Codon- optimized
53	GAGGTGCAGCTGGTGAGAGCGGCGGGCGGCCTGGTGCAGCCCGG CGGCAGCCTGAGGCTGAGCTGCGCCGCCAGCGGCTTCACCTTCAG CACCAGCGGCATGAACTGGTTCAGGCAGGCCCGCGCAAGGGCC TGGAGTGGGTGAGCTACATCAGCAGCAGCAGCGGCTTCGTGTACG CCGACAGCGTGAAGGGCAGGTTACCATCAGCAGGGACAACGCCC AGAACAGCCTGTACCTGCAGATGAACAGCCTGAGGGCCGAGGACA CCGCCGTGTACTACTGCGCCAGGAGCGAGGCCGCCTTCTGGGGC CAGGGCACCTGGTGACCGTG	Humanized VH Non-codon- optimized
38	GAGGTACAGCTGGTGAGTCTGGAGGAGGCTTAGTGCAGCCTGGA AAGTCCCTGAACTCTCCTGTTTCAGCCTCTGGATTCACATTCA GTAC CTCTGGCATGCACTGGTTTCGCCAAGCTCCAGGAAAGGGGCTGGA TTGGGTTGCATACATTAGTAGTAGCAGCGGTTTCGTCTATGCAGAC GCTGTGAAGGGCCGGTTCACCATCTCCAGAGACAATGCACAGAAC ACCCTGTACCTGCAACTCAACAGTCTGAAGTCTGAAGACACTGCCA TCTATTACTGTGCAAGAAGCGAGGCTGCTTTCTGGGGCCAAGGCAC TCTGGTCACTGTCTCTTCA	Rat VH
39	GATATCGTGCTGACCCAGAGCCCCAGATCCCTGCCTGTGACACCT GGCGAGCCTGCCAGCATCAGCTGCAGAAGCAGCAAGAGCCGGCT GAGCCGGATGGGCATCACCCCCCTGAACTGGTATCTGCAGAAACC CGGCCAGTCCCCCAGCTGCTGATCTACCGGATGAGCAACAGAGC CAGCGGCGTGCCCGATAGATTTTCCGGCTCTGGAAGCGGCACCGA CTTCACCCTGAAGATCAGCAAGGTGGAAACCGAGGACGTGGGCGT	Humanized VL

	GTACTATTGCGCCCAAGTTCTGGAATACCCCCCACCTTTGGCAGC GGCACCAAGCTGGAAATCAAG	
54	GACATCGTGCTGACCCAGAGCCCCCGCAGCCTGCCCCGTGACCCCC GGCGAGCCCCGCCAGCATCAGCTGCAGGTCTCCAAGTCCAGGCTG AGCAGGATGGGCATCACCCCCCTGAACTGGTACCTGCAGAAGCCC GGCCAGAGCCCCCAGCTGCTGATCTACAGGATGAGCAACAGGGCC AGCGGCGTGCCCGACAGGTTTCAGCGGCAGCGGCAGCGGCACCGA CTTCACCCTGAAGATCAGCAAGGTGGAGACCGAGGACGTGGGCGT GTACTACTGCGCCCAAGTTCTGGAATACCCCCCACCTTCGGCAG CGGCACCAAGCTGGAGATCAAG	Humanized VL Non-codon- optimized
40	GATATTGTGTTGACTCAAGCTCCACGCTCTGTATCTGTCACTCCTG GAGAGTCAGCTTCCATCTCCTGCAGGTCTAATAAGAGTCGACTGAG TAGGATGGGCATCACTCCCTTGAATTGGTACCTTCAGAAGCCAGGA AAGTCTCCTCAGCTCCTGATATATCGGATGTCCAACCTTGCCTCAG GAGTTCCAGACAGGTTTAGTGGCAGTGGGTGAGAAACAGATTTTAC ACTGAAAATCAGTAAGGTGGAGACTGAGGATGTTGGCGTTTATTAC TGTGCACAGTTTCTAGAATATCCTCCTACGTTTCGGTTCTGGGACCA AGCTGGAGATCAAA	Rat VL
41	GGCAGCACAAAGCGGCTCTGGCAAACCTGGATCTGGCGAGGGGCAG CACCAAGGGC	Humanized Whitlow
42	GGCAGCACCAAGCGGCTCCGGCAAGCCTGGCTCTGGCGAGGGGCAG CACAAAGGGA	Rat Whitlow
43	CCCGCCGAGCCCAAGAGCCCCGACAAGACCCATACCTGCCCTCCA TGTCCTGCCCCCTCCAGTGGCTGGCCCTAGCGTGTTCTGTTCCCC CCAAAGCCCAAGGACACCCTGATGATCGCCCGGACCCCTGAAGTG ACCTGCGTGGTGGTGGATGTGTCCACGAGGATCCCGAAGTGAAG TTCAATTGGTACGTGGACGGCGTGGAAGTGCACAACGCCAAGACC AAGCCCAGAGAGGAACAGTACAACAGCACCTACCGGGTGGTGTCT GTGCTGACCGTGCTGCATCAGGACTGGCTGAACGGCAAAGAGTAC AAGTGCAAGGTGTCCAACAAGGCCCTGCCTGCCCCCATCGAGAAA ACCATCTCCAAGGCCAAGGGACAGCCCCGCGAGCCCCAGGTGTAC ACACTGCCTCCAAGCAGGGACGAGCTGACCAAGAACCAGGTCAGC CTGACCTGCCTGGTCAAAGGCTTCTATCCCAGCGACATCGCCGTG GAGTGGGAGAGCAATGGGCAGCCGGAGAACAACACTACAAGACCACG CCTCCCGTGCTGGACTCCGACGGCTCCTTCTTCTCTACAGCAAGC TCACCGTGGACAAGAGCAGGTGGCAGCAGGGGAACGTCTTCTCAT GCTCCGTGATGCATGAGGCTCTGCACAACCACTACACGCAGAAGA GCCTCTCCCTGTCTCCGGGTAAAAAAGATCCCAAA	Humanized IgG1 spacer
44	CCTGCCGAGCCTAAGAGCCCCGACAAGACCCACACCTGTCCCCCT TGTCCTGCCCCCTCCAGTGGCTGGCCCTAGCGTGTTCTGTTCCCC CCAAAGCCCAAGGATACCCTGATGATCGCCCGGACCCCGAAGTC ACATGCGTGGTGGTGGACGTGAGCCACGAAGACCCTGAGGTCAAG TTCAACTGGTACGTGGACGGCGTGGAGGTGCATAATGCCAAGACA AAGCCGCGGGAGGAGCAGTACAACAGCACGTACCGTGTGGTCAGC GTCCTCACCGTCCTGCACCAGGACTGGCTGAATGGCAAGGAGTAC AAGTGCAAGGTCTCCAACAAGCCCTCCCAGCCCCCATCGAGAAAA CCATCTCCAAGCCAAAGGGCAGCCCCGAGAACCACAGGTGTACA CCCTGCCCCCATCCCGGGATGAGCTGACCAAGAACCAGGTCAGCC TGACCTGCCTGGTCAAAGGCTTCTATCCCAGCGACATCGCCGTGG AGTGGGAGAGCAATGGGCAGCCGGAGAACAACACTACAAGACCACGC CTCCCGTGCTGGACTCCGACGGCTCCTTCTTCTCTACAGCAAGCT CACCGTGGACAAGAGCAGGTGGCAGCAGGGGAACGTCTTCTCATG CTCCGTGATGCATGAGGCTCTGCACAACCACTACACGCAGAAGAG CCTCTCCCTGTCTCCGGGTAAAAAAGATCCCAAA	Rat IgG1 spacer
45	CCAGGTGTCCCTGACCTGCCTCGTGAAGGGCTTCTACCCCTCCGA TATCGCCGTGGAATGGGAGAGCAATGGCCAGCCCGAGAACAACATA CAAGACCACCCCCCTGTGCTGGACAGCGACGGCTCATTCTTCCT GTACAGCAAGCTGACAGTGGACAAGAGCCGGTGGCAGCAGGGCAA	Humanized IgG1Δ spacer

	CGTGTTTCAGCTGCAGCGTGATGCACGAGGCTCTGCACAACCACTA CACCCAGAAGTCCCTGAGCAGCCTGAGCCCAGGCAAGAAG	
46	CCTGCCGAGCCTAAGAGCCCCGACAAGACCCACACCTGTCCCCCT TGTCCTGCCCCCTCCAGTGGCTGGCCCTAGCGTGTTCCCTGTTCCCC CCAAAGCCCCAAGGATACCCTGATGATCGCCCGGACCCCCGAAGTC ACATGCGTGGTGGTGGACGTGAGCCACGAAGACCCTGAGGTCAAG TTCAACTGGTACGTGGACGGCGTGGAGGTGCATAATGCCAAGACA AAGCCGCGGGAGGAGCAGTACAACAGCACGTACCGTGTGGTCAGC GTCCTCACCGTCCTGCACCAGGACTGGCTGAATGGCAAGGAGTAC AAGTGCAAGGTCTCCAACAAAGCCCTCCCAGCCCCCATCGAGAAAA CCATCTCCAAAGCCAAAGGGCAGCCCCGAGAACCACAGGTGTACA CCCTGCCCCCATCCCGGGATGAGCTGACCAAGAA	Rat IgG1Δ spacer
47	ATCTACATCTGGGCCCCCTCTGGCCGGCACCTGTGGCGTGCTGCTG CTGTCTCTCGTGATCACACTGTACTGC	transmembran e domainCD8α
48	TTTTGGGTGCTGGTGGTGGTTGGTGGAGTCCTGGCTTGCTATAGCT TGCTAGTAACAGTGGCCTTTATTATTTTCTGGGTG	transmembran e domainCD28
49	AAGCGGGGCAGAAAGAAGCTGCTGTACATCTTCAAGCAGCCCTTCA TGCGGCCCCGTGCAGACCACCCAGGAAGAGGACGGCTGCTCCTGC AGATTCCCCGAGGAAGAAGAAGGCGGCTGCGAGCTG	Co-stimulatory domain4-1BB
50	AGGAGTAAGAGGAGCAGGCTCCTGCACAGTGA CTACATGAACATG ACTCCCCGCCGCCCGGGCCACCCGCAAGCATTACCAGCCCTAT GCCCCACCACGCGACTTCGCAGCCTATCGCTCCCTG	Co-stimulatory domainCD28
51	CTGCGCGTGAAGTTTTCTAGAAGCGCCGACGCCCCCTGCCTACCAG CAGGGCCAGAACCAGCTGTACAACGAGCTGAACCTGGGCAGACGG GAAGAGTACGACGTGCTGGATAAGCGGAGAGGCCGGGACCCTGA GATGGGCGGCAAGCCTAGAAGAAAGAACCCCCAGGAAGGCCTGTA TAACGAACTGCAGAAAGACAAGATGGCCGAGGCCTACAGCGAGAT CGGAATGAAGGGCGAGCGGAGAAGAGGCAAGGGCCACGATGGAC TGTACCAGGGCCTGAGCACCGCCACCAAGGACACCTATGACGCCC TGCACATGCAGGCTCTGCCCCCCAGATAA	Activation domainCD3 zeta (4-1BB)
52	AGAGTGAAGTTCAGCAGGAGCGCAGACGCCCCCGCGTACCAGCAG GGCCAGAACCAGCTCTATAACGAGCTCAATCTAGGACGAAGAGAG GAGTACGATGTTTTGGACAAGAGACGTGGCCGGGACCCTGAGATG GGGGGAAAGCCGAGAAGGAAGAACCCTCAGGAAGGCCTGTACAAT GAACTGCAGAAAGATAAGATGGCGGAGGCCTACAGTGAGATTGGG ATGAAAGGCGAGCGCCGGAGGGGCAAGGGGCACGATGGCCTTTA CCAGGGTCTCAGTACAGCCACCAAGGACACCTACGACGCCCTTCA CATGCAGGCCCTGCCCCCTCGCTGA	Activation domainCD3 zeta (CD28)

A further aspect of the invention relates to a vector comprising a nucleic acid molecule as described herein, preferably a viral vector, more preferably a gamma retroviral vector. In another aspect of the invention, the invention relates to a transposon vector, preferably a sleeping beauty vector, encoding and preferably capable of expressing the inventive CAR.

A further aspect of the invention relates to a genetically modified immune cell comprising a nucleic acid molecule or vector as described herein, and/or expressing a CAR as described herein.

In a preferred embodiment the immune cells intended for administering in treatment of the diseases mentioned herein are genetically modified with a nucleic acid as described herein, encoding and expressing the anti-CXCR5 CAR as described herein, using a "Sleeping beauty" transposon system, in particular a sleeping beauty transposase. The Sleeping Beauty transposon system is a synthetic DNA transposon designed to introduce precisely defined DNA sequences into the chromosomes of vertebrate animals, in the context of the present invention for the purposes of modifying immune cells to express the CAR as described herein. The sleeping beauty transposons combine the advantages of viruses and naked DNA. Viruses have been evolutionarily selected based on their

abilities to infect and replicate in new host cells. Simultaneously, cells have evolved major molecular defense mechanisms to protect themselves against viral infections. Avoiding the use of viruses is also important for social and regulatory reasons. The use of non-viral vectors such as the sleeping beauty system therefore avoids many, but not all, of the defenses that cells employ against vectors.

5 For this reason, the sleeping beauty system enables particularly effective and safe genetic modification of the immune cells for administration to a patient.

In further embodiments of the invention, CrispR/Cas and TALEN-mediated insertion of the CXCR5 CAR encoding nucleic acid may be employed. CrispR/Cas, known to a skilled person, which is adapted from a naturally occurring process in bacteria, may be employed to precisely and efficiently

10 edit DNA to insert the appropriate coding sequences into the immune cell, preferably T cell, of interest. Cas9, a protein that acts as a molecular pair of scissors, is guided to a specific DNA sequence by an associated RNA molecule (a guide RNA). When Cas9 arrives at its target location on the DNA, it facilitates a change in the local genetic code, affecting the function of that gene. CRISPR/Cas9 can deliver the CAR gene to a very specific site within the T cell genome, which may

15 reduce the risk of gene insertion at incorrect or undesired locations.

In one embodiment the immune cell is preferably selected from the group consisting of a T lymphocyte or an NK cell, more preferably cytotoxic T lymphocytes.

In a preferred embodiment the genetically modified immune cell comprising a nucleic acid molecule or vector as described herein, and/or expressing a CAR as described herein, is characterised in that

20 it is CD4+ and/or CD8+ T cell, preferably a mixture of CD4+ and CD8+ T cells. These T cell populations, and preferably the composition comprising both CD4+ and CD8+ transformed cells, show particularly effective cytolytic activity against various malignant B cells, such as B-NHL, preferably against those cells and/or the associated medical conditions described herein.

In a preferred embodiment the genetically modified immune cells comprising a nucleic acid molecule or vector as described herein, and/or expressing a CAR as described herein, are CD4+ and CD8+ T cells, preferably in a ration of 1:10 to 10:1, more preferably in a ratio of 5:1 to 1:5, 2:1 to 1:2 or 1:1. Administration of CXCR5-directed modified CAR-T cells expressing the CAR described herein at the ratios mentioned, preferably at a 1:1 CD4+/CD8+ ratio, lead to beneficial characteristics during treatment of the diseases mentioned herein, for example these ratios lead to improved therapeutic

30 response and reduced toxicity.

An additional and surprising aspect of the invention is an improved stability of the CAR as disclosed herein. The CAR polypeptide can readily be stored for extended periods under appropriate conditions without any loss of binding affinity.

A further aspect of the invention relates to a genetically modified immune cell as described herein for

35 use in the treatment of a medical disorder associated with the presence of pathogenic cells expressing CXCR5.

In one embodiment the medical disorder to be treated is associated with the presence of pathogenic mature B cells and/or memory B cells.

In one embodiment the medical disorder to be treated is mature B cell non-Hodgkin's lymphoma (B-NHL).

40

In other embodiments the medical disorder to be treated is a B cell derived lymphoproliferative disorder, selected preferably from the group consisting of acute lymphoblastic leukemia (B-ALL), chronic lymphocytic leukemia (CLL), follicular lymphoma (FL), mantle cell lymphoma (MCL) and diffuse large B cell lymphoma (DLBCL).

In one embodiment the medical disorder to be treated is associated with the presence of pathogenic T cells and/or T follicular helper cells.

In one embodiment the medical disorder to be treated is a T cell non-Hodgkin's lymphoma, with or without a leukemic tumor cell dissemination.

- 5 In one embodiment the medical disorder to be treated is a T cell derived lymphoproliferative disorder, selected preferably from the group consisting of angioimmunoblastic T cell lymphoma, cutaneous T cell lymphoma and T cell lymphoma with a leukemic dissemination.

A further aspect of the invention relates to a genetically modified immune cell as described herein expressing the inventive CAR for use as a medicament in the treatment of an autoantibody-
10 dependent autoimmune disease.

In a preferred embodiment the autoimmune disease is selected from systemic lupus erythematosus (SLE) or rheumatoid arthritis.

Only recently, CAR-T cells have also been discussed as a targeted approach to treat autoantibody-mediated diseases (Ellebrecht et al. (2016) Science 353:179-184). The ability to target CXCR5
15 would inhibit co-localization of autoreactive B cells and Tfh cells, which would be of great benefit for the treatment of autoimmune diseases.

Mild forms of autoimmune disease are usually initially treated with nonsteroidal anti-inflammatory drugs (NSAID) or disease-modifying anti-rheumatic drugs (DMARD). More severe forms of
20 rheumatoid arthritis (RA) and systemic lupus erythematosus (SLE), involving organ dysfunction due to active disease, usually are treated with steroids in conjunction with strong immunosuppressive agents such as cyclophosphamide, a cytotoxic agent that targets cycling cells. Only recently belimumab, an antibody targeting the cytokine BAFF, which is found at elevated levels in serum of patients with autoimmune diseases, received approval by the Food and Drug Administration (FDA) for its use in SLE.

25 However, only newly formed B cells rely on BAFF for survival in humans, whereas memory B cells and plasma cells are less susceptible to selective BAFF inhibition (Jacobi et al. (2010) Arthritis Rheum 62:201–210). For rheumatoid arthritis (RA), TNF inhibitors were the first licensed biological agents, followed by abatacept, rituximab, and tocilizumab and others: they suppress key inflammatory pathways involved in joint inflammation and destruction, which, however, comes at the
30 price of an elevated infection risk due to relative immunosuppression (Chan et al. (2010) Nat Rev Immunol 10:301–316, Keyser (2011) Curr Rheumatol Rev 7:77–87).

Rituximab, a monoclonal antibody that depletes B cells from the circulation, in particular has increasingly been prescribed for the treatment of RA but also for granulomatosis with polyangiitis and other antineutrophil cytoplasmic antibody-associated vasculitides. But rituximab is not without
35 risks and carries a similar adverse event risk rate as cyclophosphamide (Shah et al. (2015) ImmunoTargets and Therapy 4:173-183). Hence, more fine-tuned and longer-lasting approaches targeting autoreactive B cells and autoantibody responses are warranted.

The invention relates further to methods of treatment of the medical conditions described herein, comprising typically the administration of a therapeutically effective amount of the CAR, or immune
40 cell expressing said CAR, to a patient in need of said treatment.

DETAILED DESCRIPTION OF THE INVENTION*Chimeric Antigen Receptors:*

According to the present invention, a chimeric antigen receptor polypeptide (CAR), comprises an extracellular antigen-binding domain, comprising an antibody or antibody fragment that binds a target antigen, a transmembrane domain, and an intracellular domain. CARs are typically described as comprising an extracellular ectodomain (antigen-binding domain) derived from an antibody and an endodomain comprising signaling modules derived from T cell signaling proteins.

In a preferred embodiment, the ectodomain preferably comprises variable regions from the heavy and light chains of an immunoglobulin configured as a single-chain variable fragment (scFv). The scFv is preferably attached to a hinge region that provides flexibility and transduces signals through an anchoring transmembrane moiety to an intracellular signaling domain. The transmembrane domains originate preferably from either CD8 α or CD28. In the first generation of CARs the signaling domain consists of the zeta chain of the TCR complex. The term "generation" refers to the structure of the intracellular signaling domains. Second generation CARs are equipped with a single costimulatory domain originated from CD28 or 4-1BB. Third generation CARs already include two costimulatory domains, e.g. CD28, 4-1BB, ICOS or OX40, CD3 zeta. The present invention preferably relates to a second or third generation CAR.

In various embodiments, genetically engineered receptors that redirect cytotoxicity of immune effector cells toward B cells are provided. These genetically engineered receptors referred to herein as chimeric antigen receptors (CARs). CARs are molecules that combine antibody-based specificity for a desired antigen (e.g., CXCR5) with a T cell receptor-activating intracellular domain to generate a chimeric protein that exhibits a specific anti-CXCR5 cellular immune activity. As used herein, the term, "chimeric," describes being composed of parts of different proteins or DNAs from different origins.

CARs contemplated herein, comprise an extracellular domain (also referred to as a binding domain or antigen-binding domain) that binds to CXCR5, a transmembrane domain, and an intracellular domain, or intracellular signaling domain. Engagement of the anti-CXCR5 antigen binding domain of the CAR with CXCR5 on the surface of a target cell results in clustering of the CAR and delivers an activation stimulus to the CAR-containing cell. The main characteristic of CARs are their ability to redirect immune effector cell specificity, thereby triggering proliferation, cytokine production, phagocytosis or production of molecules that can mediate cell death of the target antigen expressing cell in a major histocompatibility complex (MHC) independent manner, exploiting the cell specific targeting abilities of monoclonal antibodies, soluble ligands or cell specific co-receptors.

In various embodiments, a CAR comprises an extracellular binding domain that comprises a humanized CXCR5-specific binding domain; a transmembrane domain; one or more intracellular signaling domains. In particular embodiments, a CAR comprises an extracellular binding domain that comprises a humanized anti-CXCR5 antigen binding fragment thereof; one or more spacer domains; a transmembrane domain; one or more intracellular signaling domains.

The "extracellular antigen-binding domain" or "extracellular binding domain" are used interchangeably and provide a CAR with the ability to specifically bind to the target antigen of interest, CXCR5. The binding domain may be derived either from a natural, synthetic, semi-synthetic, or recombinant source. Preferred are scFv domains.

"Specific binding" is to be understood as via one skilled in the art, whereby the skilled person is clearly aware of various experimental procedures that can be used to test binding and binding

specificity. Methods for determining equilibrium association or equilibrium dissociation constants are known in the art. Some cross-reaction or background binding may be inevitable in many protein-protein interactions; this is not to detract from the "specificity" of the binding between CAR and epitope. "Specific binding" describes binding of an anti-CXCR5 antibody or antigen binding fragment thereof (or a CAR comprising the same) to CXCR5 at greater binding affinity than background binding. The term "directed against" is also applicable when considering the term "specificity" in understanding the interaction between antibody and epitope.

An "antigen (Ag)" refers to a compound, composition, or substance that can stimulate the production of antibodies or a T cell response in an animal. In particular embodiments, the target antigen is an epitope of a CXCR5 polypeptide. An "epitope" refers to the region of an antigen to which a binding agent binds. Epitopes can be formed both from contiguous amino acids or noncontiguous amino acids juxtaposed by tertiary folding of a protein.

"Single-chain Fv" or "scFv" antibody fragments comprise the VH and VL domains of an antibody, wherein these domains are present in a single polypeptide chain and in either orientation {e.g., VL-VH or VH-VL}. Generally, the scFv polypeptide further comprises a polypeptide linker between the VH and VL domains which enables the scFv to form the desired structure for antigen binding. In preferred embodiments, a CAR contemplated herein comprises antigen-specific binding domain that is an scFv and may be a murine, human or humanized scFv. Single chain antibodies may be cloned from the V region genes of a hybridoma specific for a desired target. In particular embodiments, the antigen-specific binding domain that is a humanized scFv that binds a human CXCR5 polypeptide. An illustrative example of a variable heavy chain that is suitable for constructing anti-CXCR5 CARs contemplated herein include, but are not limited to the amino acid sequence set forth in SEQ ID NO: 9. An illustrative example of a variable light chain that is suitable for constructing anti-CXCR5 CARs contemplated herein include, but is not limited to the amino acid sequence set forth in SEQ ID NO: 11.

Antibodies and antibody fragments:

The CAR comprises an extracellular antigen-binding domain, comprising an antibody or antibody fragment that binds CXCR5 polypeptide. Antibodies or antibody fragments of the invention therefore include, but are not limited to polyclonal, monoclonal, bispecific, human, humanized or chimeric antibodies, single chain fragments (scFv), single variable fragments (ssFv), single domain antibodies (such as VHH fragments from nanobodies), Fab fragments, F(ab')₂ fragments, fragments produced by a Fab expression library, anti-idiotypic antibodies and epitope-binding fragments or combinations thereof of any of the above, provided that they retain similar binding properties of the CAR described herein, preferably comprising the corresponding CDRs, or VH and VL regions as described herein. Also mini-antibodies and multivalent antibodies such as diabodies, triabodies, tetravalent antibodies and peptabodies can be used in a method of the invention. The immunoglobulin molecules of the invention can be of any class (i.e. IgG, IgE, IgM, IgD and IgA) or subclass of immunoglobulin molecules. Thus, the term antibody, as used herein, also includes antibodies and antibody fragments comprised by the CAR of the invention, either produced by the modification of whole antibodies or synthesized de novo using recombinant DNA methodologies.

As used herein, an "antibody" generally refers to a protein consisting of one or more polypeptides substantially encoded by immunoglobulin genes or fragments of immunoglobulin genes. Where the term "antibody" is used, the term "antibody fragment" may also be considered to be referred to. The recognized immunoglobulin genes include the kappa, lambda, alpha, gamma, delta, epsilon and mu constant region genes, as well as the myriad immunoglobulin variable region genes. Light chains are

classified as either kappa or lambda. Heavy chains are classified as gamma, mu, alpha, delta, or epsilon, which in turn define the immunoglobulin classes, IgG, IgM, IgA, IgD, and IgE, respectively. The basic immunoglobulin (antibody) structural unit is known to comprise a tetramer or dimer. Each tetramer is composed of two identical pairs of polypeptide chains, each pair having one "light" (L) (about 25 kD) and one "heavy" (H) chain (about 50-70 kD). The N-terminus of each chain defines a variable region of about 100 to 110 or more amino acids, primarily responsible for antigen recognition. The terms "variable light chain" and "variable heavy chain" refer to these variable regions of the light and heavy chains respectively. Optionally, the antibody or the immunological portion of the antibody, can be chemically conjugated to, or expressed as, a fusion protein with other proteins.

The CARs of the invention are intended to bind against mammalian, in particular human, protein targets. The use of protein names may correspond to either mouse or human versions of a protein.

Affinities of binding domain polypeptides and CAR proteins according to the present disclosure can be readily determined using conventional techniques, e.g., by competitive ELISA (enzyme-linked immunosorbent assay), or by binding association, or displacement assays using labeled ligands, or using a surface-plasmon resonance device such as the Biacore.

Humanized antibodies comprising one or more CDRs of antibodies of the invention or one or more CDRs derived from said antibodies can be made using any methods known in the art. For example, four general steps may be used to humanize a monoclonal antibody. These are: (1) determining the nucleotide and predicted amino acid sequence of the starting antibody light and heavy variable domains (2) designing the humanized antibody, i.e., deciding which antibody framework region to use during the humanizing process (3) the actual humanizing methodologies/techniques and (4) the transfection and expression of the humanized antibody. See, for example, U.S. Pat. Nos. 4,816,567; 5,807,715; 5,866,692; 6,331,415; 5,530,101; 5,693,761; 5,693,762; 5,585,089; 6,180,370; 5,225,539; 6,548,640.

The term humanized antibody means that at least a portion of the framework regions, and optionally a portion of CDR regions or other regions involved in binding, of an immunoglobulin is derived from or adjusted to human immunoglobulin sequences. The humanized, chimeric or partially humanized versions of the mouse monoclonal antibodies can, for example, be made by means of recombinant DNA technology, departing from the mouse and/or human genomic DNA sequences coding for H and L chains or from cDNA clones coding for H and L chains. Humanized forms of mouse antibodies can be generated by linking the CDR regions of non-human antibodies to human constant regions by recombinant DNA techniques (Queen et al., 1989; WO 90/07861). Alternatively the monoclonal antibodies used in the method of the invention may be human monoclonal antibodies. Human antibodies can be obtained, for example, using phage-display methods (WO 91/17271; WO 92/01047).

As used herein, humanized antibodies refer also to forms of non-human (e.g. murine, camel, llama, shark) antibodies that are specific chimeric immunoglobulins, immunoglobulin chains, or fragments thereof (such as Fv, Fab, Fab', F(ab')₂ or other antigen-binding subsequences of antibodies) that contain minimal sequence derived from non-human immunoglobulin.

As used herein, human or humanized antibody or antibody fragment means an antibody having an amino acid sequence corresponding to that of an antibody produced by a human and/or has been made using any of the techniques for making human antibodies known in the art or disclosed herein. Human antibodies or fragments thereof can be selected by competitive binding experiments, or otherwise, to have the same epitope specificity as a particular mouse antibody. The humanized

antibodies of the present invention surprisingly share the useful functional properties of the mouse antibodies to a large extent. Human polyclonal antibodies can also be provided in the form of serum from humans immunized with an immunogenic agent. Optionally, such polyclonal antibodies can be concentrated by affinity purification using amyloid fibrillar and/or non-fibrillar polypeptides or fragments thereof as an affinity reagent. Monoclonal antibodies can be obtained from serum according to the technique described in WO 99/60846.

Variable Regions and CDRs

A variable region of an antibody refers to the variable region of the antibody light chain or the variable region of the antibody heavy chain, either alone or in combination. The variable regions of the heavy and light chain each consist of four framework regions (FR) connected by three complementarity determining regions (CDRs) also known as hypervariable regions. The CDRs in each chain are held together in close proximity by the FRs and, with the CDRs from the other chain, contribute to the formation of the antigen-binding site of antibodies.

There are a number of techniques available for determining CDRs, such as an approach based on cross-species sequence variability (i.e., Kabat *et al.* Sequences of Proteins of Immunological Interest, (5th ed., 1991, National Institutes of Health, Bethesda Md.)); and an approach based on crystallographic studies of antigen-antibody complexes (Al-Lazikani *et al.* (1997) J. Molec. Biol. 273:927-948). Alternative approaches include the IMGT international ImMunoGeneTics information system, (Marie-Paule Lefranc). The Kabat definition is based on sequence variability and is the most commonly used method. The Chothia definition is based on the location of the structural loop regions, wherein the AbM definition is a compromise between the two used by Oxford Molecular's AbM antibody modelling software (refer www.bioinf.org.uk : Dr. Andrew C.R. Martin's Group). As used herein, a CDR may refer to CDRs defined by one or more approach, or by a combination of these approaches.

In some embodiments, the invention provides an antibody or fragment thereof incorporated into a CAR, wherein said antibody or fragment thereof comprises at least one CDR, at least two, at least three, or more CDRs that are substantially identical to at least one CDR, at least two, at least three, or more CDRs of the antibody of the invention. Other embodiments include antibodies which have at least two, three, four, five, or six CDR(s) that are substantially identical to at least two, three, four, five or six CDRs of the antibodies of the invention or derived from the antibodies of the invention. In some embodiments, the at least one, two, three, four, five, or six CDR(s) are at least about 70%, 75%, 85%, 86%, 87%, 88%, 89%, 90%, 95%, 96%, 97%, 98%, or 99% identical to at least one, two or three CDRs of the antibody of the invention. It is understood that, for purposes of this invention, binding specificity and/or overall activity is generally retained, although the extent of activity may vary compared to said antibody (may be greater or lesser).

Additional components of the CAR

In certain embodiments, the CARs contemplated herein may comprise linker residues between the various domains, added for appropriate spacing and conformation of the molecule, for example a linker comprising an amino acid sequence that connects the VH and VL domains and provides a spacer function compatible with interaction of the two sub-binding domains so that the resulting polypeptide retains a specific binding affinity to the same target molecule as an antibody that comprises the same light and heavy chain variable regions. CARs contemplated herein, may comprise one, two, three, four, or five or more linkers. In particular embodiments, the length of a linker is about 1 to about 25 amino acids, about 5 to about 20 amino acids, or about 10 to about 20 amino acids, or any intervening length of amino acids.

Illustrative examples of linkers include glycine polymers; glycine-serine polymers; glycine-alanine polymers; alanine-serine polymers; and other flexible linkers known in the art, such as the Whitlow linker. Glycine and glycine-serine polymers are relatively unstructured, and therefore may be able to serve as a neutral tether between domains of fusion proteins such as the CARs described herein.

5 In particular embodiments, the binding domain of the CAR is followed by one or more "spacers" or "spacer polypeptides," which refers to the region that moves the antigen binding domain away from the effector cell surface to enable proper cell/cell contact, antigen binding and activation. In certain embodiments, a spacer domain is a portion of an immunoglobulin, including, but not limited to, one or more heavy chain constant regions, e.g., CH2 and CH3. The spacer domain can include the
10 amino acid sequence of a naturally occurring immunoglobulin hinge region or an altered immunoglobulin hinge region. In one embodiment, the spacer domain comprises the CH2 and CH3 domains of IgG1 or IgG4. In one embodiment the Fc-binding domain of such a spacer/hinge region is mutated in a manner that prevents binding of the CAR to Fc-receptors expressed on macrophages and other innate immune cells.

15 The binding domain of the CAR may in some embodiments be followed by one or more "hinge domains," which play a role in positioning the antigen binding domain away from the effector cell surface to enable proper cell/cell contact, antigen binding and activation. A CAR may comprise one or more hinge domains between the binding domain and the transmembrane domain (TM). The hinge domain may be derived either from a natural, synthetic, semi-synthetic, or recombinant
20 source. The hinge domain can include the amino acid sequence of a naturally occurring immunoglobulin hinge region or an altered immunoglobulin hinge region. Illustrative hinge domains suitable for use in the CARs described herein include the hinge region derived from the extracellular regions of type 1 membrane proteins such as CD8 alpha, CD4, CD28, PD1, CD 152, and CD7, which may be wild-type hinge regions from these molecules or may be altered. In another
25 embodiment, the hinge domain comprises a PD1, CD 152, or CD8 alpha hinge region.

The "transmembrane domain" is the portion of the CAR that fuses the extracellular binding portion and intracellular signaling domain and anchors the CAR to the plasma membrane of the immune effector cell. The TM domain may be derived either from a natural, synthetic, semi-synthetic, or recombinant source. The TM domain may be derived from the alpha, beta or zeta chain of the T-cell
30 receptor, CD3ε, CD3ζ, CD4, CD5, CD8 alpha, CD9, CD 16, CD22, CD27, CD28, CD33, CD37, CD45, CD64, CD80, CD86, CD 134, CD 137, CD 152, CD 154, and PD1. In one embodiment, the CARs contemplated herein comprise a TM domain derived from CD8 alpha or CD28

In particular embodiments, CARs contemplated herein comprise an intracellular signaling domain. An "intracellular signaling domain," refers to the part of a CAR that participates in transducing the
35 message of effective anti-CXCR5 CAR binding to a human CXCR5 polypeptide into the interior of the immune effector cell to elicit effector cell function, e.g., activation, cytokine production, proliferation and cytotoxic activity, including the release of cytotoxic factors to the CAR-bound target cell, or other cellular responses elicited with antigen binding to the extracellular CAR domain. The term "effector function" refers to a specialized function of an immune effector cell. Effector function of
40 the T cell, for example, may be cytolytic activity or help or activity including the secretion of a cytokine. Thus, the term "intracellular signaling domain" refers to the portion of a protein which transduces the effector function signal and that directs the cell to perform a specialized function. CARs contemplated herein comprise one or more co-stimulatory signaling domains to enhance the efficacy, expansion and/or memory formation of T cells expressing CAR receptors. As used herein,
45 the term, "co-stimulatory signaling domain" refers to an intracellular signaling domain of a co-stimulatory molecule. Co-stimulatory molecules are cell surface molecules other than antigen

receptors or Fc receptors that provide a second signal required for efficient activation and function of T lymphocytes upon binding to antigen.

In one embodiment, the CAR comprises an intracellular domain, which comprises a co-stimulatory domain and a signalling (activation) domain. The CAR construct may therefore include an intracellular signaling domain (CD3 zeta) of the native T cell receptor complex and one or more co-stimulatory domains that provide a second signal to stimulate full T cell activation. Co-stimulatory domains are thought to increase CAR T cell cytokine production and facilitate T cell replication and T cell persistence. Co-stimulatory domains have also been shown to potentially prevent CAR T cell exhaustion, increase T cell antitumor activity, and enhance survival of CAR T cells in patients. As a non-limiting example, CAR constructs with the 4-1BB co-stimulatory domain have been associated with gradual, sustained expansion and effector function, increased persistence, and enriched central memory cells (TCM) in the T cell subset composition in preclinical studies. 4-1BB is a member of the tumor necrosis factor (TNF) superfamily, and it is an inducible glycoprotein receptor in vivo that is primarily expressed on antigen-activated CD4 and CD8 T cells. As a non-limiting example, CD28 is member of the immunoglobulin (Ig) superfamily. It is constitutively expressed on resting and activated CD4 and CD8 T cells and plays a critical role in T cell activation by stimulating the PI3K-AKT signal transduction pathway. In one embodiment, the intracellular domain comprises both 4-1BB and CD28 co-stimulatory domains. Other co-stimulatory domains comprise ICOS and OX40 that can be combined with the CD3 zeta signaling (activation) domain.

Polypeptides

"Peptide" "polypeptide", "polypeptide fragment" and "protein" are used interchangeably, unless specified to the contrary, and according to conventional meaning, i.e., as a sequence of amino acids. Polypeptides are not limited to a specific length, e.g., they may comprise a full length protein sequence or a fragment of a full length protein, and may include post-translational modifications of the polypeptide, for example, glycosylations, acetylations, phosphorylations and the like, as well as other modifications known in the art, both naturally occurring and non-naturally occurring.

In various embodiments, the CAR polypeptides contemplated herein comprise a signal (or leader) sequence at the N-terminal end of the protein, which co-translationally or post-translationally directs transfer of the protein. Polypeptides can be prepared using any of a variety of well-known recombinant and/or synthetic techniques. Polypeptides contemplated herein specifically encompass the CARs of the present disclosure, or sequences that have deletions from, additions to, and/or substitutions of one or more amino acid of a CAR as disclosed herein.

An "isolated peptide" or an "isolated polypeptide" and the like, as used herein, refer to in vitro isolation and/or purification of a peptide or polypeptide molecule from a cellular environment, and from association with other components of the cell, i.e., it is not significantly associated with in vivo substances. Similarly, an "isolated cell" refers to a cell that has been obtained from an in vivo tissue or organ and is substantially free of extracellular matrix.

Nucleic acids

As used herein, the terms "polynucleotide" or "nucleic acid molecule" refers to messenger RNA (mRNA), RNA, genomic RNA (gRNA), plus strand RNA (RNA(+)), minus strand RNA (RNA(-)), genomic DNA (gDNA), complementary DNA (cDNA) or recombinant DNA. Polynucleotides include single and double stranded polynucleotides. Preferably, polynucleotides of the invention include polynucleotides or variants having at least about 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, 99% or 100%) sequence identity to any of the reference sequences

described herein, typically where the variant maintains at least one biological activity of the reference sequence. In various illustrative embodiments, the present invention contemplates, in part, polynucleotides comprising expression vectors, viral vectors, and transfer plasmids, and compositions, and cells comprising the same.

5 Polynucleotides can be prepared, manipulated and/or expressed using any of a variety of well-established techniques known and available in the art. In order to express a desired polypeptide, a nucleotide sequence encoding the polypeptide, can be inserted into appropriate vector. Examples of vectors are plasmid, autonomously replicating sequences, and transposable elements. Additional
10 exemplary vectors include, without limitation, plasmids, phagemids, cosmids, artificial chromosomes such as yeast artificial chromosome (YAC), bacterial artificial chromosome (BAC), or PI-derived artificial chromosome (PAC), bacteriophages such as lambda phage or M13 phage, and animal viruses. Examples of categories of animal viruses useful as vectors include, without limitation, retrovirus (including lentivirus), adenovirus, adeno-associated virus, herpesvirus {e.g., herpes simplex virus}, poxvirus, baculovirus, papillomavirus, and papovavirus {e.g., SV40}. Examples of
15 expression vectors are pCIneo vectors (Promega) for expression in mammalian cells; pLenti4/V5-DEST™, pLenti6/V5-DEST™, and pLenti6.2/V5-GW/lacZ (Invitrogen) for lentivirus-mediated gene transfer and expression in mammalian cells. In particular embodiments, the coding sequences of the chimeric proteins disclosed herein can be ligated into such expression vectors for the expression of the chimeric protein in mammalian cells. The "control elements" or "regulatory sequences" present in
20 an expression vector are those non-translated regions of the vector - origin of replication, selection cassettes, promoters, enhancers, translation initiation signals (Shine Dalgarno sequence or Kozak sequence) introns, a polyadenylation sequence, 5' and 3' untranslated regions - which interact with host cellular proteins to carry out transcription and translation. Such elements may vary in their strength and specificity. Depending on the vector system and host utilized, any number of suitable
25 transcription and translation elements, including ubiquitous promoters and inducible promoters may be used.

Vectors

In particular embodiments, a cell (e.g., an immune effector cell, such as a T cell) is transduced with a retroviral vector, e.g., a lentiviral vector, encoding a CAR. For example, an immune effector cell is
30 transduced with a vector encoding a CAR that comprises a humanized anti-CXCR5 antibody or antigen binding fragment that binds a CXCR5 polypeptide, with a transmembrane and intracellular signaling domain, such that these transduced cells can elicit a CAR-mediated cytotoxic response.

Retroviruses are a common tool for gene delivery. In particular embodiments, a retrovirus is used to deliver a polynucleotide encoding a chimeric antigen receptor (CAR) to a cell. As used herein, the
35 term "retrovirus" refers to an RNA virus that reverse transcribes its genomic RNA into a linear double-stranded DNA copy and subsequently covalently integrates its genomic DNA into a host genome. Once the virus is integrated into the host genome, it is referred to as a "provirus." The provirus serves as a template for RNA polymerase II and directs the expression of RNA molecules which encode the structural proteins and enzymes needed to produce new viral particles.

40 Illustrative retroviruses suitable for use in particular embodiments, include, but are not limited to: Moloney murine leukemia virus (M-MuLV), Moloney murine sarcoma virus (MoMSV), Harvey murine sarcoma virus (HaMuSV), murine mammary tumor virus (MuMTV), gibbon ape leukemia virus (GaLV), feline leukemia virus (FLV), spumavirus, Friend murine leukemia virus, Murine Stem Cell Virus (MSCV) and Rous Sarcoma Virus (RSV)) and lenti virus.

As used herein, the term "lentivirus" refers to a group (or genus) of complex retroviruses. Illustrative lentiviruses include, but are not limited to: HIV (human immunodeficiency virus; including HIV type 1, and HIV type 2); visna-maedi virus (VMV) virus; the caprine arthritis-encephalitis virus (CAEV); equine infectious anemia virus (EIAV); feline immunodeficiency virus (FIV); bovine immune deficiency virus (BIV); and simian immunodeficiency virus (SIV). In one embodiment, HIV based vector backbones (i.e., HIV cis-acting sequence elements) are preferred. In particular embodiments, a lentivirus is used to deliver a polynucleotide comprising a CAR to a cell.

The term "vector" is used herein to refer to a nucleic acid molecule capable transferring or transporting another nucleic acid molecule. The transferred nucleic acid is generally linked to, e.g., inserted into, the vector nucleic acid molecule. A vector may include sequences that direct autonomous replication in a cell, or may include sequences sufficient to allow integration into host cell DNA. Useful vectors include, for example, plasmids (e.g., DNA plasmids or RNA plasmids), transposons, cosmids, bacterial artificial chromosomes, and viral vectors. Useful viral vectors include, e.g., replication defective retroviruses and lentiviruses. In further embodiments of the invention, CrispR/Cas and TALEN-mediated insertion of the CXCR5 CAR encoding nucleic acid may be employed. Appropriate vectors for CrispR/Cas and TALEN-mediated insertion are known to a skilled person.

As will be evident to one of skill in the art, the term "viral vector" is widely used to refer either to a nucleic acid molecule (e.g., a transfer plasmid) that includes virus-derived nucleic acid elements that typically facilitate transfer of the nucleic acid molecule or integration into the genome of a cell or to a viral particle that mediates nucleic acid transfer. Viral particles will typically include various viral components and sometimes also host cell components in addition to nucleic acid(s).

The term viral vector may refer either to a virus or viral particle capable of transferring a nucleic acid into a cell or to the transferred nucleic acid itself. Viral vectors and transfer plasmids contain structural and/or functional genetic elements that are primarily derived from a virus. The term "retroviral vector" refers to a viral vector or plasmid containing structural and functional genetic elements, or portions thereof, that are primarily derived from a retrovirus.

In a preferred embodiment the invention therefore relates to a method for transfecting cells with an expression vector encoding a CAR. For example, in some embodiments, the vector comprises additional sequences, such as sequences that facilitate expression of the CAR, such a promoter, enhancer, poly-A signal, and/or one or more introns. In preferred embodiments, the CAR-coding sequence is flanked by transposon sequences, such that the presence of a transposase allows the coding sequence to integrate into the genome of the transfected cell.

In some embodiments, the genetically transformed cells are further transfected with a transposase that facilitates integration of a CAR coding sequence into the genome of the transfected cells. In some embodiments the transposase is provided as DNA expression vector. However, in preferred embodiments, the transposase is provided as an expressible RNA or a protein such that long-term expression of the transposase does not occur in the transgenic cells. For example, in some embodiments, the transposase is provided as an mRNA (e.g., an mRNA comprising a cap and poly-A tail). Any transposase system may be used in accordance with the embodiments of the present invention. However, in some embodiments, the transposase is salmonid-type Tel -like transposase (SB). For example, the transposase can be the so called "Sleeping beauty" transposase, see e.g., U.S. Patent 6,489,458, incorporated herein by reference. In some embodiments, the transposase is an engineered enzyme with increased enzymatic activity. Some specific examples of transposases include, without limitation, SB 10, SB 11 or SB 100X transposase (see, e.g., Mates et al, 2009, Nat

Genet. 41(6):753-61, or US9228180, herein incorporated by reference). For example, a method can involve electroporation of cells with an mRNA encoding an SB 10, SB 11 or SB 100X transposase.

Sequence Variants:

Sequence variants of the claimed nucleic acids, proteins, antibodies, antibody fragments and/or CARs, for example those defined by % sequence identity, that maintain similar binding properties of the invention are also included in the scope of the invention. Such variants, which show alternative sequences, but maintain essentially the same binding properties, such as target specificity, as the specific sequences provided are known as functional analogues, or as functionally analogous.

Sequence identity relates to the percentage of identical nucleotides or amino acids when carrying out a sequence alignment.

The recitation "sequence identity" as used herein refers to the extent that sequences are identical on a nucleotide-by-nucleotide basis or an amino acid-by-amino acid basis over a window of comparison. Thus, a "percentage of sequence identity" may be calculated by comparing two optimally aligned sequences over the window of comparison, determining the number of positions at which the identical nucleic acid base (e.g., A, T, C, G, I) or the identical amino acid residue (e.g., Ala, Pro, Ser, Thr, Gly, Val, Leu, He, Phe, Tyr, Trp, Lys, Arg, His, Asp, Glu, Asn, Gln, Cys and Met) occurs in both sequences to yield the number of matched positions, dividing the number of matched positions by the total number of positions in the window of comparison (i.e., the window size), and multiplying the result by 100 to yield the percentage of sequence identity. Included are nucleotides and polypeptides having at least about 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, 99% or 100% sequence identity to any of the reference sequences described herein, typically where the polypeptide variant maintains at least one biological activity of the reference polypeptide.

It will be appreciated by those of ordinary skill in the art that, as a result of the degeneracy of the genetic code, there are many nucleotide sequences that encode a polypeptide as described herein. Some of these polynucleotides bear minimal homology or sequence identity to the nucleotide sequence of any native gene. Nonetheless, polynucleotides that vary due to differences in codon usage are specifically contemplated by the present invention. Deletions, substitutions and other changes in sequence that fall under the described sequence identity are also encompassed in the invention.

Protein sequence modifications, which may occur through substitutions, are also included within the scope of the invention. Substitutions as defined herein are modifications made to the amino acid sequence of the protein, whereby one or more amino acids are replaced with the same number of (different) amino acids, producing a protein which contains a different amino acid sequence than the primary protein. Substitutions may be carried out that preferably do not significantly alter the function of the protein. Like additions, substitutions may be natural or artificial. It is well known in the art that amino acid substitutions may be made without significantly altering the protein's function. This is particularly true when the modification relates to a "conservative" amino acid substitution, which is the substitution of one amino acid for another of similar properties. Such "conserved" amino acids can be natural or synthetic amino acids which because of size, charge, polarity and conformation can be substituted without significantly affecting the structure and function of the protein. Frequently, many amino acids may be substituted by conservative amino acids without deleteriously affecting the protein's function.

In general, the non-polar amino acids Gly, Ala, Val, Ile and Leu; the non-polar aromatic amino acids Phe, Trp and Tyr; the neutral polar amino acids Ser, Thr, Cys, Gln, Asn and Met; the positively

charged amino acids Lys, Arg and His; the negatively charged amino acids Asp and Glu, represent groups of conservative amino acids. This list is not exhaustive. For example, it is well known that Ala, Gly, Ser and sometimes Cys can substitute for each other even though they belong to different groups.

- 5 Substitution variants have at least one amino acid residue in the antibody molecule removed and a different residue inserted in its place. The sites of greatest interest for substitutional mutagenesis include the hypervariable regions, but FR alterations are also contemplated. If such substitutions result in a change in biological activity, then more substantial changes, denominated "exemplary substitutions" in the table immediately below, or as further described below in reference to amino
- 10 acid classes, may be introduced and the products screened.

Potential Amino Acid Substitutions:

Original residue	Preferred conservative substitutions	Examples of exemplary substitutions
Ala (A)	Val	Val; Leu; Ile
Asp (D)	Glu	Glu; Asn
Asn (N)	Gln	Gln; His; Asp, Lys; Arg
Asp (D)	Glu	Glu; Asn
Cys (C)	Ser	Ser; Ala
Gln (Q)	Asn	Asn, Glu
Glu (E)	Asp	Asp; Gln
Gly (G)	Ala	Ala
His (H)	Arg	Asn; Gln; Lys; Arg
Ile (I)	Leu	Leu; Val; Met; Ala; Phe; Norleucine
Leu (L)	Ile	Norleucine; Ile; Val; Met; Ala; Phe
Lys (K)	Arg	Arg; Gln; Asn
Met (M)	Leu	Leu; Phe; Ile
Phe (F)	Tyr	Leu; Val; Ile; Ala; Tyr
Pro (P)	Ala	Ala
Ser (S)	Thr	Thr
Thr (T)	Ser	Ser
Trp (W)	Tyr	Tyr; Phe
Tyr (Y)	Phe	Trp; Phe; Thr; Ser
Val (V)	Leu	Ile; Leu; Met; Phe; Ala; Norleucine

- Substantial modifications in the biological properties of the antibody are accomplished by selecting substitutions that differ significantly in their effect on maintaining (a) the structure of the polypeptide backbone in the area of the substitution, for example, as a sheet or helical conformation, (b) the
- 15 charge or hydrophobicity of the molecule at the target site, or (c) the bulk of the side chain.

- Conservative amino acid substitutions are not limited to naturally occurring amino acids, but also include synthetic amino acids. Commonly used synthetic amino acids are omega amino acids of various chain lengths and cyclohexyl alanine which are neutral non-polar analogs; citrulline and
- 20 methionine sulfoxide which are neutral non-polar analogs, phenylglycine which is an aromatic neutral analog; cysteic acid which is a negatively charged analog and ornithine which is a positively

charged amino acid analog. Like the naturally occurring amino acids, this list is not exhaustive, but merely exemplary of the substitutions that are well known in the art.

Genetically modified cells and Immune cells

5 The present invention contemplates, in particular embodiments, cells genetically modified to express the CARs contemplated herein, for use in the treatment of B cell related conditions. As used herein, the term "genetically engineered" or "genetically modified" refers to the addition of extra genetic material in the form of DNA or RNA into the total genetic material in a cell. The terms, "genetically modified cells," "modified cells," and, "redirected cells," are used interchangeably. As used herein, the term "gene therapy" refers to the introduction--permanently or transiently-- of extra genetic
10 material in the form of DNA or RNA into the total genetic material in a cell that restores, corrects, or modifies expression of a gene, or for the purpose of expressing a therapeutic polypeptide, e.g., a CAR. In particular embodiments, the CARs contemplated herein are introduced and expressed in immune effector cells so as to redirect their specificity to a target antigen of interest, e.g., a CXCR5 polypeptide.

15 An "immune cell" or "immune effector cell" is any cell of the immune system that has one or more effector functions (e.g., cytotoxic cell killing activity, secretion of cytokines, induction of ADCC and/or CDC). An immune effector cell can be also differentiated from iPSCs (induced pluripotent stem cells)

Immune effector cells of the invention can be autologous/autogeneic ("self) or non-autologous ("non-self," e.g., allogeneic, syngeneic or xenogeneic). "Autologous," as used herein, refers to cells from
20 the same subject, and represent a preferred embodiment of the invention. "Allogeneic," as used herein, refers to cells of the same species that differ genetically to the cell in comparison.

"Syngeneic," as used herein, refers to cells of a different subject that are genetically identical to the cell in comparison. "Xenogeneic," as used herein, refers to cells of a different species to the cell in comparison. In preferred embodiments, the cells of the invention are autologous or allogeneic.

25 Illustrative immune effector cells used with the CARs contemplated herein include T lymphocytes. The terms "T cell" or "T lymphocyte" are art-recognized and are intended to include thymocytes, immature T lymphocytes, mature T lymphocytes, resting T lymphocytes, cytokine-induced killer cells (CIK cells) or activated T lymphocytes. Cytokine-induced killer (CIK) cells are typically CD3- and CD56-positive, non-major histocompatibility complex (MHC)-restricted, natural killer (NK)-like T
30 lymphocytes. A T cell can be a T helper (Th; CD4+ T cell) cell, for example a T helper 1 (Th1) or a T helper 2 (Th2) cell. The T cell can be a cytotoxic T cell (CTL; CD8+ T cell), CD4+CD8+ T cell, CD4 CD8 T cell, or any other subset of T cells. Other illustrative populations of T cells suitable for use in particular embodiments include naive T cells and memory T cells and stem cell-like memory cells (TSCM).

35 For example, when reintroduced back to patients after autologous cell transplantation, the T cells modified with the CAR of the invention as described herein may recognize and kill tumor cells. CIK cells may have enhanced cytotoxic activity compared to other T cells, and therefore represent a preferred embodiment of an immune cell of the present invention.

40 As would be understood by the skilled person, other cells may also be used as immune effector cells with the CARs as described herein. In particular, immune effector cells also include NK cells, NKT cells, neutrophils, and macrophages. Immune effector cells also include progenitors of effector cells wherein such progenitor cells can be induced to differentiate into an immune effector cells in vivo or in vitro. Progenitors can be iPSCs that become immune effector cells under defined culture conditions.

The present invention provides methods for making the immune effector cells which express the CAR contemplated herein. In one embodiment, the method comprises transfecting or transducing immune effector cells isolated from an individual such that the immune effector cells express one or more CAR as described herein. In certain embodiments, the immune effector cells are isolated from an individual and genetically modified without further manipulation in vitro. Such cells can then be directly re-administered into the individual. In further embodiments, the immune effector cells are first activated and stimulated to proliferate in vitro prior to being genetically modified to express a CAR. In this regard, the immune effector cells may be cultured before and/or after being genetically modified (i.e., transduced or transfected to express a CAR contemplated herein).

In particular embodiments, prior to in vitro manipulation or genetic modification of the immune effector cells described herein, the source of cells is obtained from a subject. In particular embodiments, the CAR-modified immune effector cells comprise T cells. T cells can be obtained from a number of sources including, but not limited to, peripheral blood mononuclear cells, bone marrow, lymph nodes tissue, cord blood, thymus issue, tissue from a site of infection, ascites, pleural effusion, spleen tissue, and tumors. In certain embodiments, T cells can be obtained from a unit of blood collected from a subject using any number of techniques known to the skilled person, such as sedimentation, e.g., FICOLL™ separation, antibody-conjugated bead-based methods such as MACS™ separation (Miltenyi). In one embodiment, cells from the circulating blood of an individual are obtained by apheresis. The apheresis product typically contains lymphocytes, including T cells, monocytes, granulocyte, B cells, other nucleated white blood cells, red blood cells, and platelets. In one embodiment, the cells collected by apheresis may be washed to remove the plasma fraction and to place the cells in an appropriate buffer or media for subsequent processing. The cells can be washed with PBS or with another suitable solution that lacks calcium, magnesium, and most, if not all other, divalent cations. As would be appreciated by those of ordinary skill in the art, a washing step may be accomplished by methods known to those in the art, such as by using a semiautomated flow through centrifuge. For example, the Cobe 2991 cell processor, the Baxter CytoMate, or the like. After washing, the cells may be resuspended in a variety of biocompatible buffers or other saline solution with or without buffer. In certain embodiments, the undesirable components of the apheresis sample may be removed in the cell directly resuspended culture media.

In certain embodiments, T cells are isolated from peripheral blood mononuclear cells (PBMCs) by lysing the red blood cells and depleting the monocytes, for example, by centrifugation through a PERCOLL™ gradient. A specific subpopulation of T cells can be further isolated by positive or negative selection techniques. One method for use herein is cell sorting and/or selection via negative magnetic immunoadherence or flow cytometry that uses a cocktail of monoclonal antibodies directed to cell surface markers present on the cells negatively selected.

PBMC may be directly genetically modified to express CARs using methods contemplated herein. In certain embodiments, after isolation of PBMC, T lymphocytes are further isolated and in certain embodiments, both cytotoxic and helper T lymphocytes can be sorted into naive, memory, and effector T cell subpopulations either before or after genetic modification and/or expansion. CD8+ cells can be obtained by using standard methods. In some embodiments, CD8+ cells are further sorted into naive, central memory, and effector cells by identifying cell surface antigens that are associated with each of those types of CD8+ cells.

In some embodiments, the immune cell of the present invention, for example the T cells described herein, can be obtained from inducible pluripotent stem cells (iPSCs) using methods known to a skilled person.

Accepted approaches for producing CAR T cells rely on the genetic modification and expansion of mature circulating T-cells. Such processes utilize autologous T cells and reduce risk of graft-versus-host (GvHD) disease from allogeneic T cells through endogenous TCR expression as well as rejection through MHC incompatibility. As an alternative, direct in vitro differentiation of engineered T cells from pluripotent stem cells, such as inducible pluripotent stem cells, provides an essentially unlimited source of cells that can be genetically modified to express the CAR of the present invention. In some embodiments, a so-called master iPSC line can be maintained, which represents a renewable source for consistently and repeatedly manufacturing homogeneous cell products. In some embodiments, the transformation of a master iPSC cell line with the CAR encoding nucleic acid is contemplated, prior to expansion and differentiation to the desired immune cell, preferably T cell. T lymphocytes can for example be generated from iPSCs, such that iPSCs could be modified with the CAR encoding nucleic acids and subsequently expanded and differentiated to T cells for administration to the patient. Differentiation to the appropriate immune cell, such a T cell, could also be conducted from the iPSCs before transformation with CAR encoding nucleic acids and expansion prior to administration. All possible combinations of iPSC expansion, genetic modification and expansion to provide suitable numbers of cells for administration are contemplated in the invention.

The immune effector cells, such as T cells, can be genetically modified following isolation using known methods, or the immune effector cells can be activated and expanded (or differentiated in the case of progenitors) in vitro prior to being genetically modified. In a particular embodiment, the immune effector cells, such as T cells, are genetically modified with the chimeric antigen receptors contemplated herein (e.g., transduced with a viral vector comprising a nucleic acid encoding a CAR) and then are activated and expanded in vitro. In various embodiments, T cells can be activated and expanded before or after genetic modification to express a CAR, using methods as described, for example, in U.S. Patents 6,352,694; 6,534,055; 6,905,680; 6,692,964; 5,858,358; 6,887,466; 6,905,681 ; 7, 144,575; 7,067,318; 7, 172,869; 7,232,566; 7, 175,843; 5,883,223; 6,905,874; 6,797,514; 6,867,041; and U.S. Patent Application Publication No. 20060121005.

In a further embodiment, a mixture of, e.g., one, two, three, four, five or more, different expression vectors can be used in genetically modifying a donor population of immune effector cells wherein each vector encodes a different chimeric antigen receptor protein as contemplated herein. The resulting modified immune effector cells forms a mixed population of modified cells, with a proportion of the modified cells expressing more than one different CAR proteins.

In one embodiment, the invention provides a method of storing genetically modified murine, human or humanized CAR protein expressing immune effector cells which target a CXCR5 protein, comprising cryopreserving the immune effector cells such that the cells remain viable upon thawing. A fraction of the immune effector cells expressing the CAR proteins can be cryopreserved by methods known in the art to provide a permanent source of such cells for the future treatment of patients afflicted with the B cell related condition. When needed, the cryopreserved transformed immune effector cells can be thawed, grown and expanded for more such cells.

Compositions and Formulations

The compositions contemplated herein may comprise one or more polypeptides, polynucleotides, vectors comprising same, genetically modified immune effector cells, etc., as contemplated herein. Compositions include, but are not limited to pharmaceutical compositions. A "pharmaceutical composition" refers to a composition formulated in pharmaceutically-acceptable or physiologically-acceptable solutions for administration to a cell or an animal, either alone, or in combination with one or more other modalities of therapy. It will also be understood that, if desired, the compositions of the

invention may be administered in combination with other agents as well, such as, e.g., cytokines, growth factors, hormones, small molecules, chemotherapeutics, pro-drugs, drugs, antibodies, or other various pharmaceutically-active agents. There is virtually no limit to other components that may also be included in the compositions, provided that the additional agents do not adversely affect the ability of the composition to deliver the intended therapy.

The phrase "pharmaceutically acceptable" is employed herein to refer to those compounds, materials, compositions, and/or dosage forms which are, within the scope of sound medical judgment, suitable for use in contact with the tissues of human beings and animals without excessive toxicity, irritation, allergic response, or other problem or complication, commensurate with a reasonable benefit/risk ratio.

As used herein "pharmaceutically acceptable carrier, diluent or excipient" includes without limitation any adjuvant, carrier, excipient, glidant, sweetening agent, diluent, preservative, dye/colorant, flavor enhancer, surfactant, wetting agent, dispersing agent, suspending agent, stabilizer, isotonic agent, solvent, surfactant, or emulsifier which has been approved by the United States Food and Drug Administration as being acceptable for use in humans or domestic animals. Exemplary pharmaceutically acceptable carriers include, but are not limited to, to sugars, such as lactose, glucose and sucrose; starches, such as corn starch and potato starch; cellulose, and its derivatives, such as sodium carboxymethyl cellulose, ethyl cellulose and cellulose acetate; tragacanth; malt; gelatin; talc; cocoa butter, waxes, animal and vegetable fats, paraffins, silicones, bentonites, silicic acid, zinc oxide; oils, such as peanut oil, cottonseed oil, safflower oil, sesame oil, olive oil, corn oil and soybean oil; glycols, such as propylene glycol; polyols, such as glycerin, sorbitol, mannitol and polyethylene glycol; esters, such as ethyl oleate and ethyl laurate; agar; buffering agents, such as magnesium hydroxide and aluminum hydroxide; alginic acid; pyrogen-free water; isotonic saline; Ringer's solution; ethyl alcohol; phosphate buffer solutions; and any other compatible substances employed in pharmaceutical formulations.

In particular embodiments, compositions of the present invention comprise an amount of CAR-expressing immune effector cells contemplated herein. As used herein, the term "amount" refers to "an amount effective" or "an effective amount" of a genetically modified therapeutic cell, e.g., T cell, to achieve a beneficial or desired prophylactic or therapeutic result, including clinical results.

A "prophylactically effective amount" refers to an amount of a genetically modified therapeutic cell effective to achieve the desired prophylactic result. Typically but not necessarily, since a prophylactic dose is used in subjects prior to or at an earlier stage of disease, the prophylactically effective amount is less than the therapeutically effective amount. The term prophylactic does not necessarily refer to a complete prohibition or prevention of a particular medical disorder. The term prophylactic also refers to the reduction of risk of a certain medical disorder occurring or worsening in its symptoms.

A "therapeutically effective amount" of a genetically modified therapeutic cell may vary according to factors such as the disease state, age, sex, and weight of the individual, and the ability of the stem and progenitor cells to elicit a desired response in the individual. A therapeutically effective amount is also one in which any toxic or detrimental effects of the virus or transduced therapeutic cells are outweighed by the therapeutically beneficial effects. The term "therapeutically effective amount" includes an amount that is effective to "treat" a subject {e.g., a patient}. When a therapeutic amount is indicated, the precise amount of the compositions of the present invention to be administered can be determined by a physician with consideration of individual differences in age, weight, tumor size, extent of infection or metastasis, and condition of the patient (subject).

It can generally be stated that a pharmaceutical composition comprising the T cells described herein may be administered at a dosage of 10^2 to 10^{10} cells/kg body weight, preferably 10^5 to 10^7 cells/kg body weight, including all integer values within those ranges. The number of cells will depend upon the ultimate use for which the composition is intended as will the type of cells included therein. For uses provided herein, the cells are generally in a volume of a liter or less, can be 500 mLs or less, even 250 mLs or 100 mLs or less. Hence the density of the desired cells is typically greater than 10^6 cells/ml and generally is greater than 10^7 cells/ml, generally 10^8 cells/ml or greater. The clinically relevant number of immune cells can be apportioned into multiple infusions that cumulatively equal or exceed 10^5 , 10^6 , 10^7 , 10^8 , 10^9 , 10^{10} , 10^{11} , or 10^{12} cells. In some aspects of the present invention, particularly since all the infused cells will be redirected to a particular target antigen, lower numbers of cells may be administered. CAR expressing cell compositions may be administered multiple times at dosages within these ranges. The cells may be allogeneic, syngeneic, xenogeneic, or autologous to the patient undergoing therapy.

Generally, compositions comprising the cells activated and expanded as described herein may be utilized in the treatment and prevention of diseases that arise in individuals who are immunocompromised. In particular, compositions comprising the CAR-modified T cells contemplated herein are used in the treatment of B cell malignancies. The CAR-modified T cells of the present invention may be administered either alone, or as a pharmaceutical composition in combination with carriers, diluents, excipients, and/or with other components such as IL-2 or other cytokines or cell populations. In particular embodiments, pharmaceutical compositions contemplated herein comprise an amount of genetically modified T cells, in combination with one or more pharmaceutically or physiologically acceptable carriers, diluents or excipients.

Pharmaceutical compositions of the present invention comprising a CAR-expressing immune effector cell population, such as T cells, may comprise buffers such as neutral buffered saline, phosphate buffered saline and the like; carbohydrates such as glucose, mannose, sucrose or dextrans, mannitol; proteins; polypeptides or amino acids such as glycine; antioxidants; chelating agents such as EDTA or glutathione; adjuvants (e.g., aluminum hydroxide); and preservatives. Compositions of the present invention are preferably formulated for parenteral administration, e.g., intravascular (intravenous or intraarterial), intraperitoneal or intramuscular administration.

The liquid pharmaceutical compositions, whether they be solutions, suspensions or other like form, may include one or more of the following: sterile diluents such as water for injection, saline solution, preferably physiological saline, Ringer's solution, isotonic sodium chloride, fixed oils such as synthetic mono or diglycerides which may serve as the solvent or suspending medium, polyethylene glycols, glycerin, propylene glycol or other solvents; antibacterial agents such as benzyl alcohol or methyl paraben; antioxidants such as ascorbic acid or sodium bisulfite; chelating agents such as ethylenediaminetetraacetic acid; buffers such as acetates, citrates or phosphates and agents for the adjustment of tonicity such as sodium chloride or dextrose. The parenteral preparation can be enclosed in ampoules, disposable syringes or multiple dose vials made of glass or plastic. An injectable pharmaceutical composition is preferably sterile.

In a particular embodiment, compositions contemplated herein comprise an effective amount of CAR-expressing immune effector cells, alone or in combination with one or more therapeutic agents. Thus, the CAR-expressing immune effector cell compositions may be administered alone or in combination with other known cancer treatments, such as radiation therapy, chemotherapy, transplantation, immunotherapy, hormone therapy, photodynamic therapy, etc. The compositions may also be administered in combination with antibiotics. Such therapeutic agents may be accepted in the art as a standard treatment for a particular disease state as described herein, such as a

particular cancer. Exemplary therapeutic agents contemplated include cytokines, growth factors, steroids, NSAIDs, DMARDs, anti-inflammatories, chemotherapeutics, radiotherapeutics, therapeutic antibodies, or other active and ancillary agents.

Therapeutic Methods

5 The genetically modified immune effector cells contemplated herein provide improved methods of adoptive immunotherapy for use in the treatment of medical disorders associated with the presence of pathogenic cells expressing CXCR5 that include, but are not limited to immunoregulatory conditions and hematological malignancies.

10 As use herein, "medical disorders associated with the presence of pathogenic cells expressing CXCR5" refer to medical conditions, such as a cancer or autoimmune disease, in which the cells involved in pathophysiology of the disease demonstrate expression of CXCR5, and preferably presentation of CXCR5 on the cell surface. The expression of CXCR5 can be determined by various methods known to a skilled person, for example by isolating cells from a patient and assessing these by PCR using primers directed CXCR5 transcripts, immune-staining with anti CXCR5 antibodies, or
15 by analysis by flow cytometry. Such pathogenic cells may typically be pathogenic mature B cells and/or memory B cells, and/or pathogenic T cells and/or T follicular helper cells.

In particular embodiments, compositions comprising CAR-modified T cells contemplated herein are used in the treatment of hematologic malignancies, including but not limited to B cell malignancies such as, for example, non-Hodgkin's lymphoma (NHL), such as B cell NHL or T cell non-Hodgkin's
20 lymphoma, with or without a leukemic tumor cell dissemination.

Non-Hodgkin lymphoma encompasses a large group of cancers of lymphocytes (white blood cells). Non-Hodgkin lymphomas can occur at any age and are often marked by lymph nodes that are larger than normal, fever, and weight loss. Non-Hodgkin lymphomas can also present on extranodal sites, such as the central nervous system, mucosal tissues including lung, intestine, colon and gut. There
25 are many different types of non-Hodgkin lymphoma. For example, non-Hodgkin's lymphoma can be divided into aggressive (fast-growing) and indolent (slow-growing) types.

Non-Hodgkin lymphomas can be derived from B cells and T-cells. As used herein, the term "non-Hodgkin lymphoma" includes both "B cell" and "T cell" non-Hodgkin lymphoma. B cell non-Hodgkin lymphomas (NHL) include Burkitt lymphoma, chronic lymphocytic leukemia/small lymphocytic
30 lymphoma (CLL/SLL), diffuse large B cell lymphoma, follicular lymphoma, immunoblastic large cell lymphoma, precursor B-lymphoblastic lymphoma, and mantle cell lymphoma. Lymphomas that occur after bone marrow or stem cell transplantation are usually B cell non-Hodgkin lymphomas.

T-cell lymphomas account for approximately 15 percent of all NHLs in the United States. There are many different forms of T-cell lymphomas, such as angioimmunoblastic T-cell lymphoma (AITL),
35 which is a mature T-cell lymphoma of blood or lymph vessel immunoblasts. Further forms of T cell lymphomas relate to cutaneous T cell lymphoma and T cell lymphoma with a leukemic dissemination.

Chronic lymphocytic leukemia (CLL) can also be treated with the present CAR, and is an indolent (slow-growing) cancer that causes a slow increase in immature white blood cells (B lymphocytes).
40 Cancer cells spread through the blood and bone marrow, and can also affect the lymph nodes or other organs such as the liver and spleen. CLL eventually causes the bone marrow to fail. A different presentation of the disease is called small lymphocytic lymphoma and localizes mostly to secondary lymphoid organs, e.g. lymph nodes and spleen.

In one embodiment of the invention the CAR or immune cell expressing said CAR is intended for use in the treatment of an autoimmune disease, preferably an auto-antibody-dependent autoimmune disease, preferably an autoimmune disease with an inflammatory component.

Deregulated CXCR5-expressing follicular T-helper (Tfh) cells represent an important mechanism contributing to exacerbated humoral immune responses and autoantibody production during autoimmune diseases. Hence, CXCR5-expressing Tfh cells represent a feasible target in the context of autoimmunity.

The autoimmune disease to be treated is preferably selected from Takayasu Arteritis, Giant-cell arteritis, familial Mediterranean fever, Kawasaki disease, Polyarteritis nodosa, cutaneous Polyarteritis nodosa, Hepatitis-associated arteritis, Behcet's syndrome, Wegener's granulomatosis, ANCA-vasculitides, Churg-Strauss syndrome, microscopic polyangiitis, Vasculitis of connective tissue diseases, Hennoch-Schönlein purpura, Cryoglobulinemic vasculitis, Cutaneous leukocytoclastic angiitis, Tropical aortitis, Sarcoidosis, Cogan's syndrome, Wiskott-Aldrich Syndrome, Lepromatous arteritis, Primary angiitis of the CNS, Thromboangiitis obliterans, Paraneoplastic arteritis, Urticaria, Dego's disease, Myelodysplastic syndrome, Erythema elevatum diutinum, Hyperimmunoglobulin D, Allergic Rhinitis, Asthma bronchiale, chronic obstructive pulmonary disease, periodontitis, Rheumatoid Arthritis, atherosclerosis, Amyloidosis, Morbus Chron, Colitis ulcerosa, Autoimmune Myositis, Diabetes mellitus, Guillain-Barre Syndrome, histiocytosis, Osteoarthritis, atopic dermatitis, periodontitis, chronic rhinosinusitis, Psoriasis, psoriatic arthritis, Microscopic colitis, Pulmonary fibrosis, glomerulonephritis, Whipple's disease, Still's disease, erythema nodosum, otitis, cryoglobulinemia, Sjogren's syndrome, Lupus erythematosus, preferably systemic lupus erythematosus (SLE), aplastic anemia, Osteomyelofibrosis, chronic inflammatory demyelinating polyneuropathy, Kimura's disease, systemic sclerosis, chronic periaortitis, chronic prostatitis, idiopathic pulmonary fibrosis, chronic granulomatous disease, Idiopathic achalasia, bleomycin-induced lung inflammation, cytarabine-induced lung inflammation, Autoimmunthrombocytopenia, Autoimmunneutropenia, Autoimmunhemolytic anemia, Autoimmunlymphocytopenia, Chagas' disease, chronic autoimmune thyroiditis, autoimmune hepatitis, Hashimoto's Thyroiditis, atropic thyroiditis, Graves disease, Autoimmune polyglandular syndrome, Autoimmune Addison Syndrome, Pemphigus vulgaris, Pemphigus foliaceus, Dermatitis herpetiformis, Autoimmune alopecia, Vitiligo, Antiphospholipid syndrome, Myasthenia gravis, Stiff-man syndrome, Goodpasture's syndrome, Sympathetic ophthalmia, Folliculitis, Sharp syndrome and/or Evans syndrome, in particular hay fever, periodontitis, atherosclerosis, rheumatoid arthritis, most preferably SLE.

Systemic lupus erythematosus (SLE), also known as lupus, is an autoimmune disease in which the body's immune system attacks healthy tissue in various parts of the body. Symptoms vary between people and may be mild to severe. Common symptoms include painful and swollen joints, fever, chest pain, hair loss, mouth ulcers, swollen lymph nodes, feeling tired, and a red rash which is most commonly on the face.

Follicular T-helper cells (Tfh) cells have been recently discovered as the major cellular reservoir of Human Immunodeficiency Virus (HIV) among CD4+ T helper cells (Leong et al. 2017, Frontiers in Immunology, 8:622) and CAR immune cells expressing the CAR of the present invention could target the follicular reservoir of HIV-producing T helper cells. As such, the CAR of the present invention may be used in eliminating or inhibiting a reservoir of HIV-producing T helper cells in the treatment of HIV. In one embodiment, the reservoir of HIV-producing T helper cells is therefore to be considered as a group of pathogenic cells expressing CXCR5, in particular pathogenic T cells.

As used herein, the terms "individual" and "subject" are often used interchangeably and refer to any animal that exhibits a symptom of a disease, disorder, or condition that can be treated with the gene therapy vectors, cell-based therapeutics, and methods disclosed elsewhere herein. In preferred embodiments, a subject includes any animal that exhibits symptoms of a disease, disorder, or condition of the hematopoietic system, e.g., a B cell malignancy, that can be treated with the cell-based therapeutics and methods disclosed herein. Suitable subjects include laboratory animals (such as mouse, rat, rabbit, or guinea pig), farm animals, and domestic animals or pets (such as a cat or dog). Non-human primates and, preferably, human patients, are included. Typical subjects include human patients that have a B cell malignancy, have been diagnosed with a B cell malignancy, or are at risk or having a B cell malignancy.

As used herein "treatment" or "treating," includes any beneficial or desirable effect on the symptoms or pathology of a disease or pathological condition, and may include even minimal reductions in one or more measurable markers of the disease or condition being treated. Treatment can involve optionally either the reduction or amelioration of symptoms of the disease or condition, or the delaying of the progression of the disease or condition. "Treatment" does not necessarily indicate complete eradication or cure of the disease or condition, or associated symptoms thereof.

As used herein, "prevent," and similar words such as "prevented," "preventing" or "prophylactic" etc., indicate an approach for preventing, inhibiting, or reducing the likelihood of the occurrence or recurrence of, a disease or condition. It also refers to delaying the onset or recurrence of a disease or condition or delaying the occurrence or recurrence of the symptoms of a disease or condition. As used herein, "prevention" and similar words also includes reducing the intensity, effect, symptoms and/or burden of a disease or condition prior to onset or recurrence of the disease or condition.

In one embodiment, a method of treating a B cell related condition in a subject in need thereof comprises administering an effective amount, e.g., therapeutically effective amount of a composition comprising genetically modified immune effector cells contemplated herein. The quantity and frequency of administration will be determined by such factors as the condition of the patient, and the type and severity of the patient's disease, although appropriate dosages may be determined by clinical trials.

The administration of the compositions contemplated herein may be carried out in any convenient manner, including by aerosol inhalation, injection, ingestion, transfusion, implantation or transplantation. In a preferred embodiment, compositions are administered parenterally. The phrases "parenteral administration" and "administered parenterally" as used herein refers to modes of administration other than enteral and topical administration, usually by injection, and includes, without limitation, intravascular, intravenous, intramuscular, intraarterial, intrathecal, intracapsular, intraorbital, intratumoral, intracardiac, intradermal, intraperitoneal, transtracheal, subcutaneous, subcuticular, intraarticular, subcapsular, subarachnoid, intraspinal and intrasternal injection and infusion. In one embodiment, the compositions contemplated herein are administered to a subject by direct injection into a tumor, lymph node, or site of infection.

FIGURES

The invention is demonstrated by way of example by the following figures. The figures are to be considered as providing a further description of potentially preferred embodiments that enhance the support of one or more non-limiting embodiments of the invention.

Brief description of the figures:

Figure 1: Schematic representation of preferred CAR structures.

Figure 2: Schematic representation of preferred CAR constructs H28, R28, HBB1, HBB2, and H28BB.

Figure 3: List of preferred constructs and potential combinations of the various structural elements of the CARs as described herein.

5 **Figure 4:** Sequence comparisons between the mAb binding regions and the preferred humanized sequences employed in the present CAR.

Figure 5: Sequence depiction of the DNA sequence encoding the mAb binding regions hHC.

Figure 6: Sequence depiction of the DNA sequence encoding the mAb binding region hLC.

Figure 7: GeneArt™ Plasmid with the humanized and rat CXCR5-CAR Sequence.

10 **Figure 8:** Gel electrophoresis of the construct and vectors after restriction.

Figure 9: Confirmation by flow cytometry of CXCR5 CAR-expression on human T cells following retroviral transduction.

Figure 10: CXCR5 expression on the cell types assessed in the functional assays.

15 **Figure 11:** Co-cultures of CAR-transduced human T cells with different target cell lines show specific T cell activation by distinct CXCR5+ B-NHL and control cell lines.

Figure 12: Cytotoxicity assays reveal selective killing of CXCR5-positive cell lines.

Figure 13. CXCR5 redirected CAR-T cells are effective against B-cell non Hodgkin's lymphoma (B-NHL) in a xenografted NSG mouse model.

20 **Figure 14:** Co-cultures of CAR-transduced human T cells with different target cell lines show specific T cell activation by distinct CXCR5+ B-NHL and control cell lines.

Figure 15: Co-cultures of CAR-transduced human T cells with CXCR5-negative primary cells of different human tissues as targets show no off-target T cell activation, whereas the CXCR5-expressing B-NHL cell line JeKo-1 mediates specific T cell activation and serves as a positive control.

25 Detailed description of the figures:

30 **Figure 1:** Schematic representation of preferred CAR structures. Depicted are the VL and VH domains of the antigen-binding domain, including the linker positioned between the VH and VL domains. Also depicted is the spacer region, positioned between the antigen-binding domain and the transmembrane domain. Also depicted are variants of the intracellular domain, comprising for example co-stimulatory and activation domains.

35 **Figure 2:** Schematic representation of preferred CAR constructs H28, R28, HBB1, HBB2, and H28BB. The preferred constructs of the invention comprise variants of the transmembrane domain, costimulatory and activation domains. Essentially, the preferred embodiments of the invention enable exchange of these various domains, preferably of those particular embodiments disclosed herein, although also encompassing additional domains with analogous functions known to one skilled in the art.

Figure 3: List of preferred constructs and potential combinations of the various structural elements of the CARs as described herein.

40 **Figure 4:** Sequence comparisons between the mAb binding regions and the preferred humanized sequences employed in the present CAR. Alignments are depicted showing sequence identity

between the rat and humanized hHC and hLC sequences. As is depicted, 89% sequence identity is evident between humanized and rat hHC sequences, and 93% sequence identity is evident between humanized and rat hLC sequences.

Figure 5: Sequence depiction of the DNA sequence encoding the mAb binding regions hHC, in particular showing a sequence comparison between the original and codon optimized (CO) DNA sequences encoding the humanized hHC.

Figure 6: Sequence depiction of the DNA sequence encoding the mAb binding region hLC, in particular showing a sequence comparison between the original and codon optimized (CO) DNA sequences encoding the humanized hLC.

Figure 7: GeneArt™ Plasmid with the humanized and rat CXCR5-CAR Sequence. Excised scFV was demonstrated using gel electrophoresis.

Figure 8: Gel electrophoresis of the construct and vectors after restriction. Also depicted is a plasmid MP71 comprising the CAR-encoding construct.

Figure 9: Confirmation by flow cytometry of CXCR5 CAR-expression on human T cells following retroviral transduction: CAR Expression, construct H28, SP6, untransduced.

Figure 10: (A) CXCR5 expression on some of the cell types assessed in the functional assays. Assessed were the B-NHL cell lines DOHH-2, SU-DHL4, OCI-Ly7, and JeKo-1, the primary patient-derived MCL xenograft, the B-ALL cell lines NALM6, REH, the MM cell line NCI-H929, and the T-ALL cell line Jurkat. As can be seen from the analysis, CXCR5 was expressed on the B-NHLs DOHH-2, SU-DHL4, OCI-Ly7 and JeKo-1 cell lines. **(B)** To rule out that the CXCR5 CAR-T cells of the present invention show crossreactivity with healthy human tissues, CXCR5 expression was assessed on a panel of primary cells derived from human healthy tissues. None of the tested primary human cells (HUVEC, human umbilical vein endothelial cells; HUAEC, human umbilical artery endothelial cells; HA, human astrocytes; HN, human neurons; HPNC, human perineurial cells; HCoEpiC, human colonic epithelial cells) showed CXCR5 surface expression by anti-CXCR5 immunostaining and flow cytometry analysis. **(C)** Quantitative determination of CXCR5 density per cell on selected B-NHL cell lines (SU-DHL4, OCI-Ly7, DOHH-2, SC-1, JeKo-1, MEC-1, JVM-3), on the MM cell line (NCI-H929), on B- (REH, NALM-6) and T-ALL (Jurkat) cell lines, on the colon adenocarcinoma cell line (SW-620), and the non- or CXCR5-transfected embryonic kidney cell line (HEK293, HEK-CXCR5, respectively) was performed by employing QuantiBRITE PE calibration beads and a CXCR5-specific antibody.

Figure 11: Co-cultures of CAR-transduced human T cells with different target cell lines show specific T cell activation by distinct CXCR5+ B-NHL and control cell lines. Functional in vitro co-cultivation and IFN-gamma ELISA was performed. The levels of IFN-gamma released is indicative of T cell activation. Untransduced (UT; left bar in each series), CXCR5-CAR expressing T cells (CXCR5 (H28); middle bar in each series) and SP6 T cells (SP6; right bar in each series) were co-cultured with the target cell lines DOHH-2, SU-DHL4, OCI-Ly7, JeKo-1, NALM6, REH, NCI-H929 and Jurkat cells. DOHH-2, SU-DHL4, OCI-Ly7 and JeKo-1 target cells show specific IFN-gamma release in response to treatment with the CXCR5 CAR-T cells of the present invention. JVM-3 also shows IFN-gamma release after treatment.

Figure 12: Cytotoxicity assays reveal selective killing of CXCR5-positive cell lines; essentially no killing was seen in CXCR5-negative cell lines. Two independent functional in vitro co-cultivation and ⁵¹Cr release assays were performed. **(A, B)** DOHH-2, SU-DHL4, OCI-Ly7, SC-1 (only in **(B)**), JeKo-1 target cell lines show lysis after treatment with the inventive CAR-Ts, whereas cells not expressing CXCR5

(Nalm6 and NCI-H929) show no lysis.

Figure 13. CXCR5 redirected CAR-T cells are effective against B-cell non Hodgkin's lymphoma (B-NHL) in a xenografted NSG mouse model. To provide proof-of-concept that the strong *in vitro* activity of T cells modified with the CXCR5 CAR translates into efficient antitumor activity *in vivo*, cohorts of NOD.Cg-Prkdc^{scid} Il2rg^{tm1 Wjl}/SzJ (NSG) mice were inoculated i.v. with 5×10^5 mantle cell lymphoma cells (MCL) JeKo-1 (**Fig. 13A-C**), transduced with the luciferase gene in tandem with GFP. NSG mice do not develop T, B, and NK cells and are therefore suitable for tolerance and growth of xenotransplanted human cells. **(A)** Engraftment of MCL tumors in a xenografted NSG mouse model. Mice were challenged by i.v. transplantation of MCL cells. At day 5 after tumor inoculation, tumor cell growth was visualized by IVIS imaging. To measure onset of tumor burden, imaging was extended to 120 sec (day 0). **(B)** To follow treatment efficacy and to scale down bioluminescence intensity for better presentation, mice as in **(A)** were again imaged for 10 sec at day 0. At the same day, mice received 3×10^6 anti-CXCR5 CAR-transduced T cells (n=4), as a negative control SP6-CAR-transduced T cells (n=3) were employed (day 0). Subsequent IVIS-exposures after CAR-T cell transfer were done at 10 sec to allow better comparisons between day 0 and day 19. **(C)** Mean values of bioluminescence signals obtained from regions of interests covering the entire body of each mouse are plotted for each group at each time point (Figure 13C). While essentially all SP6 CAR treated animals had progressive lymphoma disease, characterized by strong luminescence signals over the bone marrow in hind limbs, thoracic and abdominal organs, this was clearly not the case for the CXCR5 CAR treatment group. This provides the first pre-clinical *in vivo* proof that CXCR5 CAR-T cells have anti-tumor activity to B-NHL lymphoma entities.

Figure 14: Co-cultures of CAR-transduced human T cells with different target cell lines show specific T cell activation by distinct CXCR5+ B-NHL and control cell lines. Functional *in vitro* cocultivation and IFN-gamma (upper panel), IL-2 (middle panel), and TNF-alpha (lower panel) ELISA was performed. The levels of IFN-gamma, IL-2, and TNF-alpha released are indicative of T cell activation and T cell functionality. Untransduced (UT, open bars), CXCR5-CD28 CAR (H28, red bars), CXCR5-41BB (HBB1; blue bars), CXCR5-CD28/41BB (H28BB, green bars) expressing T cells and SP6 T cells (SP6, grey bars) were co-cultured with the target cell lines JeKo-1, DOHH-2, SU-DHL4, OCI-Ly7, REH, and NCI-H929 cells. DOHH-2, SU-DHL4, OCI-Ly7 and JeKo-1 target cells show specific IFN-gamma, IL-2, and TNF-alpha release in response to treatment with the CXCR5 CAR-T cells of the present invention.

Figure 15: Co-cultures of CAR-transduced human T cells with CXCR5-negative primary cells of different human tissues as targets show no off-target T cell activation, whereas the CXCR5-expressing B-NHL cell line JeKo-1 mediates specific T cell activation and serves as a positive control. Functional *in vitro* co-cultivation and IFN-gamma ELISA was performed. Untransduced (UT, open bars), CXCR5-CD28 CAR (H28, red bars) expressing T cells and SP6 CAR T cells (SP6, grey bars) were co-cultured with the primary cells HUVECs, HUAECs, HAs, HNs, HPNCs, HCoEpiCs; with the T-ALL cell line Jurkat, and the B-NHL cell line JeKo-1. Lack of IFN-gamma release is indicative of an absent specific T cell activation in the presence of CXCR5-negative primary cells, and the CXCR5-negative T-ALL cell line Jurkat. CXCR5-CD28 CAR-T cells of the present invention show specific IFN-gamma release in response to co-cultivation with CXCR5-expressing JeKo-1 target cells.

EXAMPLES

The invention is demonstrated by way of the examples disclosed below. The examples provide technical support for and a more detailed description of potentially preferred, non-limiting embodiments of the invention.

5 In order to demonstrate the functionality and beneficial properties of the CAR described herein, the following examples are to be considered:

- co-cultures of CAR-transduced human T cells with different target cell lines show specific T cell activation by distinct CXCR5+ cell lines; readout was release of IFN-gamma as effector cytokine from T cells;

10 - cytotoxicity assays reveal selective killing of CXCR5+ cell lines; essentially no killing was seen in CXCR5-negative cell lines, e.g. Nalm6 and NCI-H929.

- In vivo experiments relate to using a xenotransplantation NSG mouse model to generate data on i) functionality, ii) off-target reactivity, iii) T cell memory, and iv) biosafety of adoptively transferred CAR-T cells against B-NHL cell lines. For B-NHL the cytolytic capacity of anti-CXCR5 CAR-T cells is
15 compared with an established anti-CD19 CAR-T cell product.

Example 1: Cloning and plasmid preparation:

The CAR scFv sequences were synthesized using GeneArt™ (Gene Synthesis Service). Restriction digestion of the synthesized sequences was carried out using NotI and CsiI (Fig. 7) in order to release the scFv insert from the GeneArt plasmid. The retroviral vector MP71, comprising additional
20 CAR sequences, was digested with NotI and CsiI to enable subsequent ligation of the isolated scFv insert into the CAR construct in the vector. The digested vector was subsequently dephosphorylated. The fragments were separated using gel electrophoresis (Fig. 8) and purified.

The CAR scFv sequence generated as described above was subsequently ligated into the purified vector comprising the additional CAR sequences (50ng) at a ratio of 3:1. Transformation of the
25 ligation mixture into MACH-1 was carried out. A control digest was conducted and the Mini-preparation was sequenced. The constructs were subsequently re-transformed into MACH-1. A maxi-preparation of the MP71-CXCR5-CAR plasmid was produced.

MP71 is a single (+)-strand-RNA-Virus. Reverse-Transcriptase converts the retroviral RNA-Genome into a DNA copy. The DNA integrates as a provirus at a random position into the target genome.

30 Through cell division the virus reproduces stably as a provirus.

MP71 comprises the following regulatory cis elements:

LTRs (= long terminal repeats) originate from the murine myeloproliferative sarcoma virus (MPSV), which contain promoters. The leader sequence of the vector is derived from the murine embryonic stem cell virus. The PRE (= posttranscriptional regulatory element) originally comes from the
35 woodchuck hepatitis virus.

MP71 has been deactivated, since retroviral genes are missing and it is thus no longer replication-competent. Structural genes were previously introduced separately into two helper plasmids in the packaging cell line. Transfection requires gag, pol and env gene products. Infectious viral particles are released into the cell culture supernatant and can be used to transduce PBLs. High transduction
40 rates with high expression rates in human PBLs can be achieved.

Example 2: Transfection and transduction:

Day 0: Seeding HEK-T(293T)- or GalV-cells for virus production in 6 well plates

Day 1: Transient 3-plasmid transfection for retrovirus production (calcium phosphate transfection). Per well, 18µg of DNA was used, in 250mM CaCl₂, 150 µl H₂O, according to standard protocols. Cells are incubated for 6 h at 37 °C, medium is exchanged, further incubation carried out for 48 h at 37 °C.

5 *Coating of 24-well non-tissue culture plates with anti-huCD3 und anti-huCD28 antibodies:*

Prepare anti-CD3/anti-CD28- antibody solution in PBS (5 µg/ml anti-CD3, 1 µg/ml anti-CD28), 0,5 ml per well. Incubate each well with 0,5 ml antibody solution for 2h at 37 °C, replace with sterile 2% BSA-solution (in water), incubation: 30 min (37 °C). Remove BSA-solution and wash wells with 2 ml PBS.

10 *Purification of PBMCs from 40 ml blood (~ 2.5x10⁷ PBMCs):*

Prepare 12,5 ml Ficoll-Gradient medium in 2x 50 ml Falcon-Tube, dilute blood with RPMI (+ 100 IU/ml Penicillin, Streptomycin) to 45 ml, mix and coat with 22.5ml Blood-Medium-mixture, centrifuge (20 min, 20 °C, 1800 rpm, RZB *648, G 17.9). Discard 15ml upper phase. Transfer remainder of the upper phase with white-milky PBMC-containing intermediate phase to a new 50 ml Falcon-Tube, fill to 45 ml with RPMI (+ 100 IU/ml Penicillin, Streptomycin) and centrifuge. Re-suspend pellets in 45 ml RPMI (+ 100 IU/ml Penicillin, Streptomycin), centrifuge, combine pellets in 10-20 ml T cell medium, stain one sample with trypan blue, count cells and add cells at a concentration of 1-1.5 x10⁶ cells/ml (T-cell medium (+ 100 IU/ml IL-2) corresponds to 400U/ml clinic-IL2) to the anti-CD3, anti-CD28 coated wells. Centrifuge remainder of PBMCs, suspend in freezing medium and store in Cryo tubes at -80 °C.

Day 3: Transduction of PBLs

Remove and filter (0,45 µm filter) viral supernatant from HEK-T- or GalV-cells. Treat stimulated PBMCs with 1.0 ml viral supernatant. Treat stimulated PBLs with 1 ml viral supernatant and centrifuge in the CD3-/ CD28-coated wells (90 min, 32 °C, 800xg). Final concentration of 100 IU/ml IL2 or 10 ng/ml IL7 und 10 ng/ml IL15, and additionally 4 µg/ml (8µl) Protamine sulfate.

Day 4: Transduction of PBLs

Filter remaining viral supernatant (4°C) and second supernatant from HEK-T- or GalV-cells (0.45 µm). Collect 1 ml supernatant from the PBLs. Adjust cytokine concentrations to 100 IU/ml IL2 or 10 ng/ml IL7 und 10 ng/ml IL15, as well as 4 µg/ml (8µl) Protamine sulfate. Centrifuge at 90 min 800xg at 32°C. 4h after transduction, PBLs are washed out the 24-well plate in to a T25 cell culture flask. Fresh medium with IL2 or IL7/IL15 is added.

Day 7 to Day 13: Culture PBLs, treat T cell medium with fresh IL2 or IL7/IL15.

Day 13: End T-cell stimulation.

Rinse PBL-cultures from the cell culture flasks, centrifugation, re-suspend pellet in T-cell medium (+ 10 IU/ml IL2 or 1ng/ml IL7/IL15).

As of Day 15: Functional assays

Example 3: Functional in vitro testing of anti-CXCR5 CAR T cells

Confirmation of CXCR5 CAR-expression on human T cells following retroviral transduction:

Evidence is provided on folding and transport of the CAR receptor in context of human T cells. The functionality of the retrovirus transduction protocol is demonstrated.

1) Human peripheral blood leukocytes were purified via a Ficoll gradient. Cells were cultured, stimulated and retrovirally transduced as described above.

Following transduction, cells were further cultured in either IL2 or IL-7/IL15 containing medium prior to the analysis of CXCR5-CAR expression.

- 5 2) Transduction rate and viability were assessed by flow cytometry (FACS) analysis. To detect CXCR5-CAR expression, cells were stained with anti-human IgG-antibody that recognizes selectively the human IgG1 or IgG4 section in the spacer region of the CAR construct. A costaining for CD3/CD8 T cells was performed.

Results are demonstrated in Figure 9.

10 Co-cultures of CAR-transduced human T cells with different target cell lines show specific T cell activation by distinct CXCR5⁺ B-NHL cell lines

The readout employed for CAR-T cell activation was release of IFN-gamma as an effector cytokine from T cells.

- 15 1) Retrovirus-transduced human T cells were generated, as detailed above. The following T cells were employed: CXCR5-CD28 CAR-receptor variant (H28), CXCR5-4-1BB CAR-receptor variant (HBB1), CXCR5-CD28/4-1BB CAR receptor variant (H288BB), SP6-negative control CAR, UT=untransduced T cells.

2) Retrovirally transduced T cells were co-cultured for 18-20 hrs in the presence of the listed cell lines or primary cells; ratio 1:1.

20

Cell line	Origin	CXCR5-positivity
DOHH-2	immunoblastic B cell lymphoma progressed from follicular centroblastic/centrocytic lymphoma (FL)	yes
OCI-Ly7	diffuse large B cell lymphoma (DLBCL), germinal center type	yes
SU-DHL4	diffuse large B cell lymphoma (DLBCL), germinal center type	yes
JeKo-1	mantle cell lymphoma (MCL), B-NHL	yes
SC-1	B follicular lymphoma (B-NHL)	yes
JVM-3	B cell chronic lymphocytic leukemia (B-CLL)	yes
NALM-6	B acute lymphoblastic leukemia (B-ALL)	no
REH	B acute lymphoblastic leukemia (B-ALL)	no
NCI-H929	multiple myeloma (MM)	no
Jurkat	T cell acute lymphoblastic leukemia (T-ALL)	no
SW-620	Colon adenocarcinoma cell	no
HEK293	Embryonic kidney cell	no

HEK-CXCR5	Embryonic kidney cell transfected with CXCR5	yes
Primary cells	Origin	CXCR5-positivity
MCL PDX	Patient-derived mantle cell lymphoma xenograft	yes
HUVEC	Human Umbilical Vein Endothelial Cells	no
HUAEC	Human Umbilical Artery Endothelial Cells	no
HA	Human Astrocytes	no
HPNC	Human Perineurial Cells	no
HCoEpiC	Human Colonic Epithelial Cells	no
HN	Human Neurons	no

3) After co-cultivation, cell-free culture supernatant was sampled and control levels of IFN-gamma were determined. The maximum release value was induced by PMA/ionomycin stimulation of effector T cells; the minimum release value was induced by T cells only.

5 4) IFN-gamma release was determined in the supernatant by ELISA.

The results are depicted in Figure 11.

Cytotoxicity assays reveal selective killing of CXCR5-positive cell lines; essentially no killing was seen in CXCR5-negative cell lines

10 The ⁵¹Cr-release assay was employed for quantitation of cytotoxic T lymphocyte activity. The assay enables the measurement of target cell cytolysis.

1) Retrovirus-transduced human T cells were generated, as detailed above. CXCR5 CAR-receptor variant (H28) was employed, in addition to SP6-negative control CAR and UT=untransduced T cells.

2) Target cells were labelled with ⁵¹Cr

15 3) CAR-T cells and labeled target cells were then co-cultured for 4 hrs and the effector cell to target cell ratio was titrated:

Effector to Target ratio:

80:1

0:1

20:1

20 10:1

5:1

2.5:1

4) Cell-free cell culture supernatant were harvested,

25 5) Supernatants were transferred to LUMA-scintillation plates, released ⁵¹Cr was measured in a gamma scintillation counter. The maximum release value was determined by target cells lysed by application to the LUMA plates; the minimum release value was determined using target cells alone.

Results are shown in Figure 12.

Example 4: *In vivo* experiments using a xenotransplantation NSG mouse model to assess adoptively transferred CAR-T cells against B-NHL cell lines

To demonstrate that CAR-T cells equipped with the diverse anti CXCR5-CAR-variants described herein have effector activity, also under in situ conditions, CXCR5+ B-NHL cell lines are transplanted via an i.v. route into NSG-mice (NOD.Cg-Prkdc^{scid} Il2rg^{tm1} Wjl/SzJ).

The CXCR5+ B-NHL cell lines are:

SU-DHL4 (DLBCL), JEKO-1 (mantle cell lymphoma), JVM3 (CLL), DOHH-2 (FL), OCI-Ly7 or SC-1.

A negative control cell line is included, that is REH (ALL), which is not destroyed by the anti CXCR5 CAR T cells in vitro, but is a target for anti CD19 CAR.

These mice are specifically suited for a xenotransplantation because they support human cell growth by cytokine provision and have no T, B, and NK cells for rejection of the transplant. The B-NHL cell lines are also stably transduced with a firefly-luciferase gene that allows for in vivo tumor cell detection by applying luciferin. Progression and distribution of tumors injected are monitored by bioluminescence imaging using the IVIS-system.

Next, when tumor cell growth is confirmed by intensity increase of the luciferase luminescent signal, at about 5-8 days after tumor cell inoculation, human CAR T-cells are administered in a titrated manner, starting with 5×10^5 up to 5×10^6 cells per recipient on an i.v. route. Anti-CXCR5 CAR T cells are compared with an anti CD19 CAR and two suitable negative controls, such as an irrelevant SP6 control and an untransduced T cell control.

In 3-5 day intervals, luminescence intensity is measured and growth retardation/progression and disappearance of tumor-cell associated signals is determined in the animals. An observation interval of 28 days is employed. A reduction in luminescence intensity and disappearance of tumor-cell associated signals indicates a therapeutic effect of the CAR T cells.

The above experiment was conducted with NOD.Cg-Prkdc^{scid} Il2rg^{tm1} Wjl/SzJ (NSG) mice by inoculating the mice i.v. with 5×10^5 mantle cell lymphoma cells (MCL) JeKo-1, transduced with the luciferase gene in tandem with GFP (Figure 13). Mice subsequently received 3×10^6 anti-CXCR5 CAR-transduced T cells (n=4), and as a negative control SP6-CAR-transduced T cells (n=3) were employed (day 0). Mean values of bioluminescence signals were obtained from regions of interests covering the entire body of each mouse. The data is plotted for each group at each time point (Figure 13C). While essentially all SP6 CAR treated animals had progressive lymphoma disease, characterized by strong luminescence signals over the bone marrow in hind limbs, thoracic and abdominal organs, this was clearly not the case for the CXCR5 CAR treatment group. This provides the first pre-clinical *in vivo* proof that CXCR5 CAR-T cells have anti-tumor activity to B-NHL lymphoma entities.

Figure 14 shows alternative CAR components with (1) 4-1BB or CD28 as a co-stimulatory component and (2) a 3rd generation CAR with CD28 and 4-1BB as co-stimulatory components, and their functional effect in co-culture experiments using CAR T cells with tumor cell lines. Specific activation of CAR-T cells by CXCR5-bearing tumor cells is demonstrated by the release of IFN-gamma, IL-2 and TNF-alpha.

While the CXCR5-CD28 (H28) CAR appears to be the most effective, the two alternative CARs, CXCR5-4-1BB (HBB1) and CXCR5-CD28/4-1BB (H28BB), also show distinct specific activity. Figure

15 shows that primary cells from healthy human tissues that do not carry CXCR5 (also refer data in Figure 10B) do not induce specific activity of CXCR5-CD28 CAR-T cells.

Example 5: Clinical approaches in particular patient collectives

5 In the human setting *in vivo*, the invention is expected to show efficacy in B-NHL patients with diffuse large B-cell lymphoma, follicular lymphoma, chronic lymphocytic leukemia, and mantle cell lymphoma. Patients with the following characteristics are to be enrolled in a clinical phase I study: i) patients with multidrug resistancies, ii) patients not eligible for allogeneic stem cell transplantation, iii) patients with co-morbidities that preclude further chemotherapies, iv) aged patients who do not tolerate chemotherapies, v) patients for salvage therapies after progressive disease has appeared
10 and multiple lines of other standard of care therapies have failed, vi) patients with rapid progressive disease after autologous stem cell transplantation, vii) patients with progressive disease after allogeneic stem cell transplantation, viii) as a bridging therapy before allogeneic stem cell transplantation, and/or ix) patients exhibiting escape variants or mutants of CD19 and/or CD20 on tumor cells, such that current antibody therapies (anti CD20, Rituximab, anti CD19, Oletuzumab,
15 BITE CD19/CD3, Blinatumomab) or anti-CD19 CAR therapies have lost/downregulated their target structures and become ineffective.

In the human setting *in vivo*, the invention is expected to show efficacy in T-NHL patients with angioimmunoblastic T-cell lymphoma, and various forms of T-cell lymphoma with leukemic dissemination, skin localization or any other organ dissemination. For these patients, selective
20 treatments do not exist, except for generalized chemotherapy regimens. Therefore, patients with following characteristics are to be enrolled in a clinical phase I study: i) patients with multidrug resistancies, ii) patients not eligible for allogeneic stem cell transplantation, iii) patients with co-morbidities that preclude further chemotherapies, iv) aged patients who do not tolerate chemotherapies, v) patients for salvage therapies after progressive disease has appeared and one
25 or two lines of other standard of care therapies have failed, vi) patients with rapid progressive disease after autologous stem cell transplantation, vii) patients with progressive disease after allogeneic stem cell transplantation, viii) as a bridging therapy before allogeneic stem cell transplantation, ix) as second line therapy for patients with pgressive disease upon one line of standard chemotherapy.

CLAIMS

1. A chimeric antigen receptor polypeptide (CAR), comprising:
 - i. an extracellular antigen-binding domain, comprising an antibody or antibody fragment that binds CXC chemokine receptor type 5 (CXCR5) protein,
 - ii. a transmembrane domain, and
 - iii. an intracellular domain.
2. A chimeric antigen receptor (CAR) polypeptide according to the preceding claim, wherein the antigen-binding domain comprises a variable heavy chain (VH), said VH comprising:
 - a heavy chain complementary determining region 1 (H-CDR1) with at least 80% sequence identity to SEQ ID NO 1 (GFTFSTSG),
 - a heavy chain complementary determining region 2 (H-CDR2) with at least 80% sequence identity to SEQ ID NO 2 (ISSSSGFV), and
 - a heavy chain complementary determining region 3 (H-CDR3) with at least 80% sequence identity to SEQ ID NO 3 (ARSEAAF),
 and a variable light chain (VL), said VL comprising:
 - a light chain complementary determining region 1 (L-CDR1) with at least 80% sequence identity to SEQ ID NO 4 (KSRLSRMGITP),
 - a light chain complementary determining region 2 (L-CDR2) with at least 66% sequence identity to SEQ ID NO 5 (RMS), and
 - a light chain complementary determining region 3 (L-CDR3) with at least 80% sequence identity to SEQ ID NO 6 (AQFLEYPPT).
3. A chimeric antigen receptor (CAR) polypeptide according to any one of the preceding claims, comprising a VH domain that comprises CDR sequences of SEQ ID NO. 1, SEQ ID No. 2 and SEQ ID NO. 3, and a VL domain that comprises CDR sequences of SEQ ID NO. 4; SEQ ID NO 5, and SEQ ID NO. 6.
4. A chimeric antigen receptor (CAR) polypeptide according to any one of the preceding claims, comprising a VH domain with at least 80% sequence identity, preferably at least 85%, 90%, 95% or with 100% sequence identity, to SEQ ID NO 7:

EVQLVESGGGLVQPGX1SLX2LSCX3ASGFTFSTSGMX4WFRQAPGKGLX5WVX6YISSSS
 GFVYADX7VKGRFTISRDNAX8LYLQX9NSLX10X11EDTAX12YYCARSEAAFWGQGTL
 VTVSS,

wherein X1: G or K, X2: R or K; X3: A or S; X4: N or H; X5: E or D; X6: S or A; X7: S or A;
 X8: S or T; X9: M or L; X10: R or K, X11: A or S; X12: V or I;

and a VL domain with at least 80% sequence identity, preferably at least 85%, 90%, 95% or with 100% sequence identity, to SEQ ID NO 8:

DIVLTQX1PRSX2PVTPGEX3ASISCRSX4KSRLSRMGITPLNWYLQKPGX5SPQLLIYRMSN
X6ASGVDPDRFSGSGSX7TDFTLKISKVETEDVGVYYCAQFLEYPPTFGSGGTKLEIK,

wherein X1: S or A; X2: L or V; X3: P or S; X4: S or N; X5: Q or K; X6: R or L; X7: G or E.

5. A chimeric antigen receptor (CAR) polypeptide according to any one of the preceding claims, comprising a VH domain according to SEQ ID NO 9
(EVQLVESGGGLVQPGGSLRLSCAASGFTFSTSGMNWFRQAPGKGLEWVSYISSSSGFVY
ADSVKGRFTISRDNAAQNSLYLQMNSLRAEDTAVYYCARSEAAFWGQGTLVTVSS), or

SEQ ID NO 10

(EVQLVESGGGLVQPGKSLKLSASGFTFSTSGMHWFRQAPGKGLDWVAYISSSSGFVY
ADAVKGRFTISRDNAAQNTLYLQLNSLKSIEDTAIYYCARSEAAFWGQGTLVTVSS)

and a VL domain according to SEQ ID NO 11

(DIVLTQSPRSLPVTPGEPASISCRSSKSRSLRMGITPLNWYLQKPGQSPQLLIYRMSNRAS
GVPDRFSGSGSGTDFTLKISKVETEDVGVYYCAQFLEYPPTFGSGGTKLEIK), or

SEQ ID NO 12

(DIVLTQAPRSVSVTPGESASISCRSNKSRLSRMGITPLNWYLQKPGKSPQLLIYRMSNLAS
GVPDRFSGSGSETDFTLKISKVETEDVGVYYCAQFLEYPPTFGSGGTKLEIK).

6. A chimeric antigen receptor (CAR) polypeptide according to any one of the preceding claims, wherein when said CAR is expressed in a genetically modified immune cell, preferably a T lymphocyte, said immune cell binds CXCR5 on the surface of a CXCR5-expressing cell and is activated, thereby inducing cytotoxic activity against said CXCR5-expressing cell, wherein the CXCR5-expressing cell is preferably a DOHH-2, OCI-Ly7, SU-DHL4, JeKo-1, JVM-3, MEC-1 and/or SC-1 cell line.

7. A chimeric antigen receptor (CAR) polypeptide according to any one of the preceding claims:

- wherein the extracellular antigen-binding domain comprises a linker polypeptide positioned between the VH and VL domains, wherein said linker is preferably selected from a Whitlow (SEQ ID NO 13; GSTSGSGKPGSGEGSTKG) or Gly-Ser (SEQ ID NO 14; SSGGGGSGGGGSGGGGS) linker, or linkers with at least 80% sequence identity to SEQ ID NO 13 or 14; and/or
- comprising additionally a spacer polypeptide positioned between the extracellular antigen-binding domain and the transmembrane domain, wherein said spacer is selected from:
 - a. IgG1 spacer (SEQ ID NO 15;
PAEPKSPDKTHTCPPCPAPPVAGPSVFLFPPKPKDTLMIARTPEVTCVVVDVS
HEDPEVKFNWYVDGVEVHNAKTKPREEQYNSTYRVVSVLTVLHQDWLNGKE
YKCKVSNKALPAPIEKTISKAKGQPREPQVYTLPPSRDELTKNQVSLTCLVKGF
YPSDIAVEWESNGQPENNYKTTTPVLDSDGSFFLYSKLTVDKSRWQQGNVFS
CSVMHEALHNHYTQKSLSLSPGKKDPK),

- b. IgG1Δ spacer (SEQ ID NO 16;
PAEPKSPDKTHTCPPCPAPPVAGPSVFLFPPKPKDTLMIARTPEVTCVVVDVS
HEDPEVKFNWYVDGVEVHNAKTKPREEQYNSTYRVVSVLTVLHQDWLNGKE
YKCKVSNKALPAPIEKTISKAKGQPREPQVYTLPPSRDELTKNQVSLTCLVKGF
YPSDIAVEWESNGQPENNYKTTTPVLDSGDSFFLYSKLTVDKSRWQQGNVFS
CSVMHEALHNHYTQKSLSSLSPGKK),
- c. IgG4 (Hi-CH2-CH3) spacer (SEQ ID NO 17;
ESKYGPPCPPCPAPEFEGGPSVFLFPPKPKDTLMISRTPEVTCVVVDVSQEDP
EVQFNWYVDGVEVHNAKTKPREEQFNSTYRVVSVLTVLHQDWLNGKEYKCK
VSNKGLPSSIEKTISKAKGQPREPQVYTLPPSQEEMTKNQVSLTCLVKGFYPSD
IAVEWESNGQPENNYKTTTPVLDSGDSFFLYSRLTVDKSRWQEGNVFSCSVM
HEALHNHYTQKSLSLSLGK),
- d. IgG4 (Hi-CH3) spacer (SEQ ID NO 18;
ESKYGPPCPPCPGQPREPQVYTLPPSQEEMTKNQVSLTCLVKGFYPSDIAVE
WESNGQPENNYKTTTPVLDSGDSFFLYSRLTVDKSRWQEGNVFSCSVMHEA
LHNHYTQKSLSLSLGK),
- e. IgG4 (Hi) spacer (SEQ ID NO 19; ESKYGPPCPPCP), or
- f. a spacer with at least 80% sequence identity to any one of SEQ ID NO 15 to 19;
and/or

- wherein the transmembrane domain is selected from a CD8α domain (SEQ ID NO 20; IYIWAPLAGTCGVLLLSLVITLYC) or a CD28 domain (SEQ ID NO 21; FWVLVVVGGLACYSLLVTVAFIIFWV), or transmembrane domains with at least 80% sequence identity to SEQ ID NO 20 or 21; and/or
- wherein the intracellular domain comprises a co-stimulatory domain selected from a 4-1BB co-stimulatory domain (SEQ ID NO 22; KRGRKKLLYIFKQPFMRPVQTTQEEDGCSCRFPEEEEGGCEL) or a CD28 co-stimulatory domain (SEQ ID NO 23; RSKRSRLLHSDYMNMTPRRPGPTRKHYPYAPPRDFAAYRSL), or a co-stimulatory domain comprising both a 4-1BB (SEQ ID NO 22) and a CD28 co-stimulatory domain (SEQ ID NO 23) arranged adjacently, or a co-stimulatory domain with at least 80% sequence identity to SEQ ID NO 22 or 23; and/or
- comprising additionally a signaling domain (activation domain), wherein said signaling domain is a CD3zeta (4-1BB or CD28) signaling domain (SEQ ID NO 24; LRVKFSRSADAPAYQQGQNQLYNELNLGRREEYDVLDRRGRDPEMGGKPRRKN PQEGLYNELQKDKMAEAYSEIGMKGERRRGKGGHDGLYQGLSTATKDTYDALHMQ ALPPR), or a signaling domain with at least 80% sequence identity to SEQ ID NO 24.

8. A chimeric antigen receptor (CAR) polypeptide according to any one of the preceding claims, comprising or consisting of a sequence according to any one of SEQ ID NO 25, 26, 27, 28 or 29.

9. An isolated nucleic acid molecule, preferably in the form of a vector, such as a viral vector or a transposon vector, preferably a sleeping beauty vector, selected from the group consisting of:
 - a) a nucleic acid molecule comprising a nucleotide sequence
 - which encodes a chimeric antigen receptor (CAR) polypeptide according to any one of the preceding claims,
 - which encodes an extracellular antigen-binding domain, a transmembrane domain, and an intracellular domain, wherein the extracellular antigen-binding domain is encoded by at least one sequence of SEQ ID NO 37, 53 or 38, and at least one sequence of SEQ ID NO 39, 54 or 40, or
 - according to SEQ ID No. 31, 32, 33, 34, or 35, and/or
 - b) a nucleic acid molecule which is complementary to a nucleotide sequence in accordance with a);
 - c) a nucleic acid molecule comprising a nucleotide sequence having sufficient sequence identity to be functionally analogous/equivalent to a nucleotide sequence according to a) or b), comprising preferably a sequence identity to a nucleotide sequence according to a) or b) of at least 80%;
 - d) a nucleic acid molecule which, as a consequence of the genetic code, is degenerated into a nucleotide sequence according to a) through c); and/or
 - e) a nucleic acid molecule according to a nucleotide sequence of a) through d) which is modified by deletions, additions, substitutions, translocations, inversions and/or insertions and is functionally analogous/equivalent to a nucleotide sequence according to a) through d).
10. A genetically modified immune cell comprising a nucleic acid molecule according to claim 9 and/or expressing a CAR according to any one of claims 1 to 8.
11. A genetically modified immune cell according to claim 10, wherein the immune cell is selected from the group consisting of a T lymphocyte and an NK cell, wherein the T lymphocyte is preferably a cytotoxic T lymphocyte.
12. A genetically modified immune cell according to any one of claims 10 or 11 for use in the treatment of a medical disorder associated with the presence of pathogenic cells expressing CXCR5, preferably pathogenic mature B cells and/or memory B cells, and/or pathogenic T cells and/or T follicular helper cells.
13. An immune cell for use as a medicament according to claim 12, wherein the medical disorder is mature B cell non-Hodgkin's lymphoma (B-NHL).
14. An immune cell for use as a medicament according to claim 12, wherein the medical disorder is a T cell non-Hodgkin's lymphoma, with or without a leukemic tumor cell dissemination.

15. An immune cell for use as a medicament according to claim 12, wherein the medical disorder is:
- a B cell derived lymphoproliferative disorder, selected from the group consisting of acute lymphoblastic leukemia (B-ALL), chronic lymphatic leukemia (CLL), follicular lymphoma (FL), mantle cell lymphoma (MCL) and diffuse large B cell lymphoma (DLBCL); or
 - a T cell derived lymphoproliferative disorder, selected from the group consisting of angioimmunoblastic T cell lymphoma, cutaneous T cell lymphoma and T cell lymphoma with a leukemic dissemination.
16. An immune cell for use as a medicament according to claim 12, wherein the medical disorder is an autoantibody-dependent autoimmune disease, preferably selected from systemic lupus erythematosus (SLE) or rheumatoid arthritis.

Fig. 1

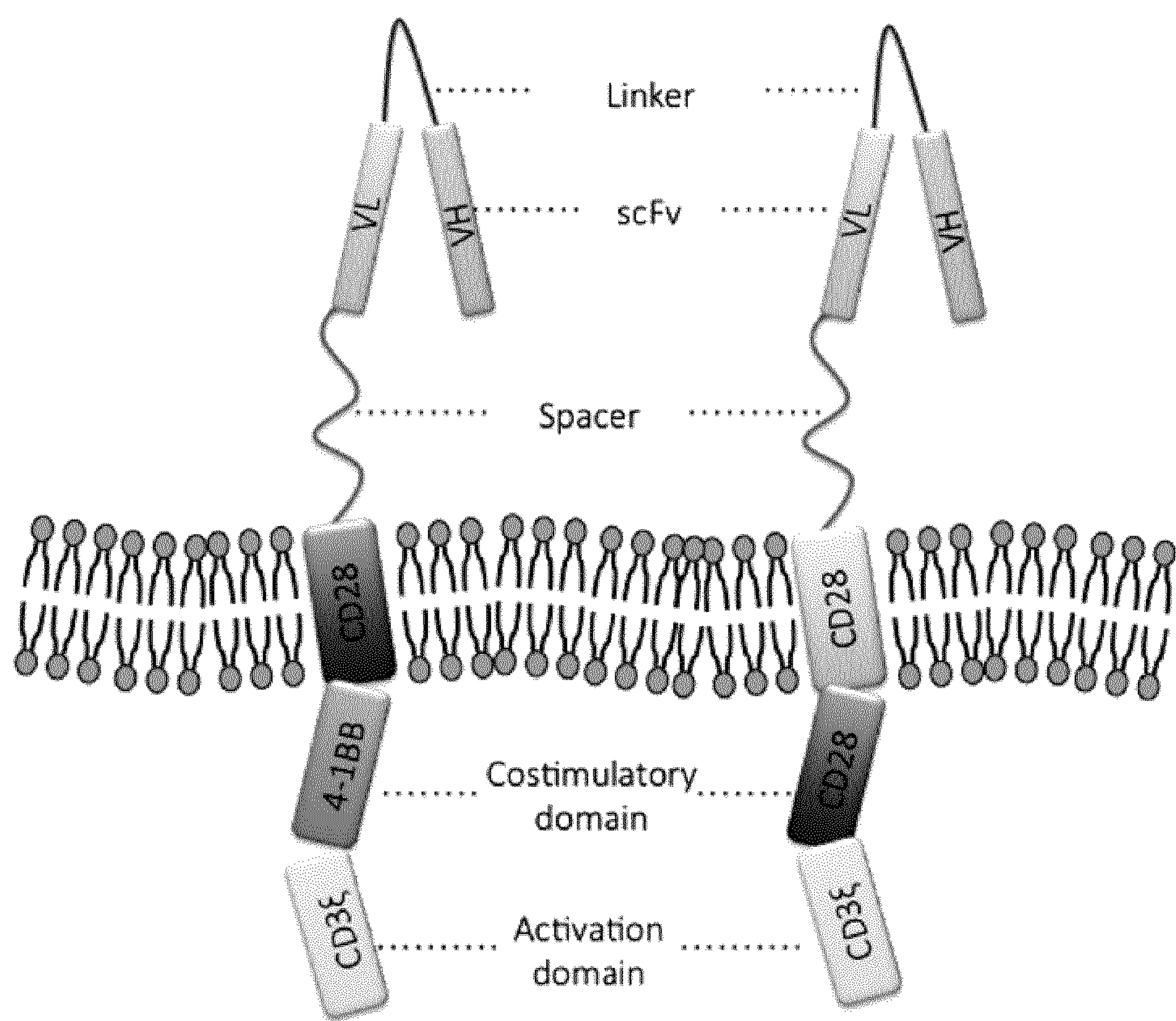


Fig. 2

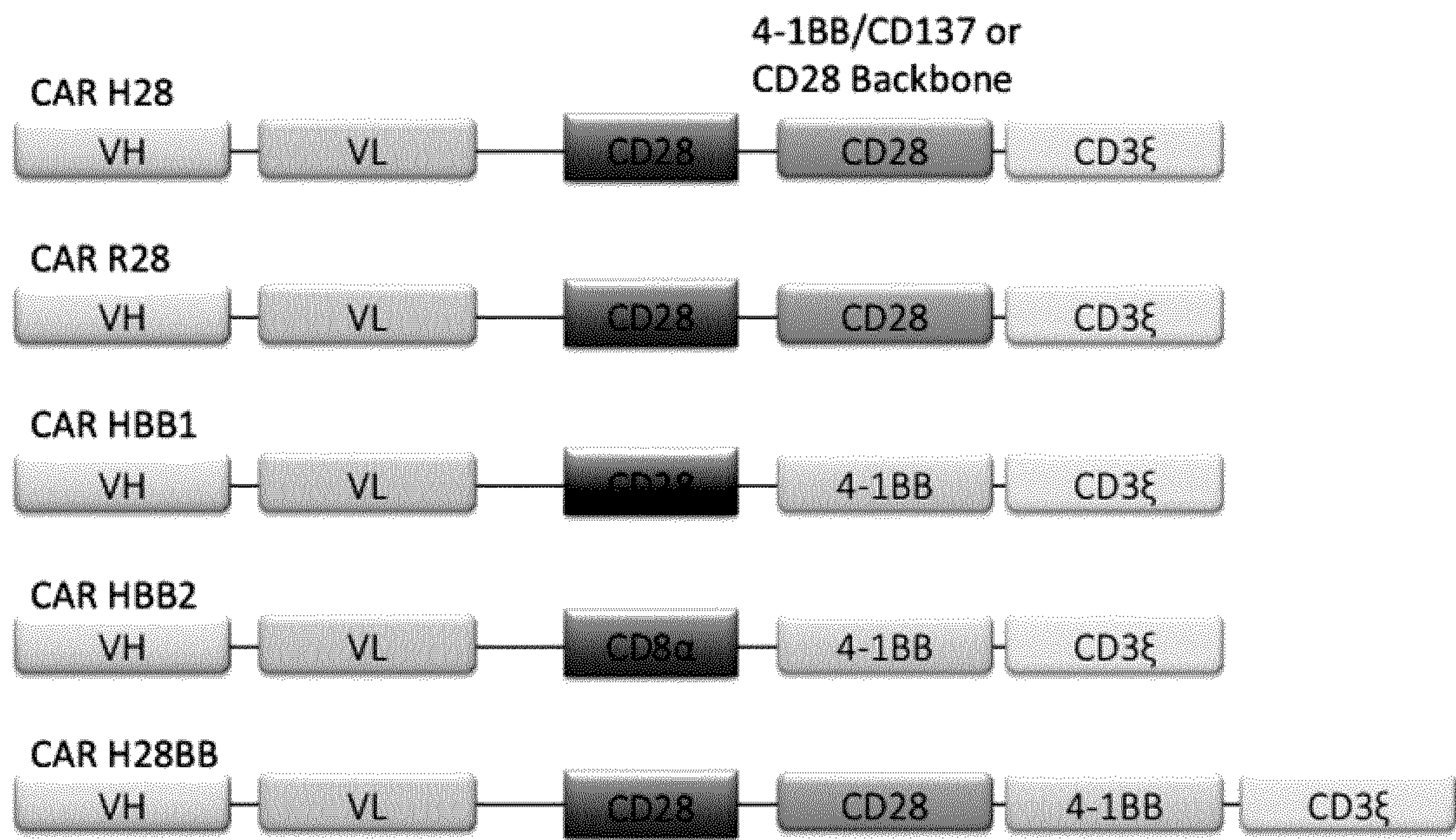


Fig. 3

	Leader	scFv	Order	Linker	Spacer	Trans- membrane domain	Co- stimulatory domain	Activation domain
H28	Igk	humanized	VH-VL	Whitlow	IgG1	CD28	CD28	CD3ξ
R28	Igk	rat	VH-VL	Whitlow	IgG1	CD28	CD28	CD3ξ
HBB1	Igk	humanized	VH-VL	Whitlow	IgG1	CD28	4-1BB	CD3ξ
HBB2	Igk	humanized	VH-VL	Whitlow	IgG1Δ	CD8α	4-1BB	CD3ξ
H28BB	Igk	humanized	VH-VL	Whitlow	IgG1	CD28	CD28 4-1BB	CD3ξ

Fig. 4

Protein alignment of hHC and hLC
rat vs. human
89% homology between humanized and rat sequence (hHC)
93% homology between humanized and rat sequence (hLC)

VH

Sequence ID: Query_228957 Length: 113 Number of Matches: 1

Range 1: 1 to 113

Graphics

▼ Next Match ▲ Previous Match

Score	Expect	Method	Identities	Positives	Gaps
214 bits(546)	4e-79	Compositional matrix adjust.	101/113(89%)	112/113(99%)	0/113(0%)
Rat 1	EVQLVESGGGLVQPGKSLKLS	CSASGFTFSTSGMHWFRQAPGKGLDWVAYISSSSGFVYA	60		
Human 1	EVQLVESGGGLVQPGSL+LSC+ASGFTFSTSGM+WFRQAPGKGL+WV+YISSSSGFVYA	EVQLVESGGGLVQPGGSLRLSCAASGFTFSTSGMNWFRQAPGKGLEWVSYISSSSGFVYA	60		
Rat 61	DAVKGRFTISRDN	AQNTLYLQLNSLKSEDTAIYYCARSEAAFWGQGLTVTVSS	113		
Human 61	D+VKGRFTISRDN	AQN+LYLQ+NSL++EDTA+YYCARSEAAFWGQGLTVTVSS	113		

VL

Sequence ID: Query_74585 Length: 112 Number of Matches: 1

Range 1: 1 to 112

Graphics

▼ Next Match ▲ Previous Match

Score	Expect	Method	Identities	Positives	Gaps
213 bits(542)	1e-78	Compositional matrix adjust.	104/112(93%)	108/112(96%)	0/112(0%)
Rat 1	DIVLTOAPRSVSVTPGESASIS	CRSNKSRSLSRMGITPLN	WYLQKPGKSPOLLIYRMSNLA	60	
Human 1	DIVLTQ+PRS+ VTPGE ASISCRS+KSRLSRMGITPLN	WYLQKPG+SPOLLIYRMSN A			
	DIVLTQSPRSLPVT	PGEPASISCRSSKSRSLSRMGITPLN	WYLQKPGQSPOLLIYRMSNRA	60	
Rat 61	SGVPDRFSGSGSETDFTLKISKVETEDVGVYYCAQFLEY	PPTFGSGTKLEIK	112		
Human 61	SGVPDRFSGSGS TDFTLKISKVETEDVGVYYCAQFLEY	PPTFGSGTKLEIK	112		

Fig. 5

hHC Alterations
Sequence was codon optimized for *homo sapiens*
90% homology to original sequence after codon optimization (CO)

VH

Sequence ID: Query_122263 Length: 339 Number of Matches: 1

Range 1: 1 to 333 [Graphics](#) [▼ Next Match](#) [▲ Previous Match](#)

Score	Expect	Identities	Gaps	Strand
433 bits(234)	4e-126	301/334(90%)	2/334(0%)	Plus/Plus
Original	1	GAGGTGCAGCTGGTGGAGAGC-GGCGGCGGCCTGGTGCAGCCCGGCGGCAGCCTGAGGCT		59
CO	1	GAGGTGCAGCTGGTGGG-ATCTGGCGGAGGACTGGTGCAGCCTGGCGGCTCTCTGAGACT		59
Original	60	GAGCTGCGCCCGCCAGCGGCTTCACCTTCAGCACCAGCGGCATGAACTGGTTCAGGCAGGC		119
CO	60	GTCTTGTCGCCCGCCAGCGGCTTCACCTTCAGCACCAGCGGCATGAACTGGTTCAGACAGGC		119
Original	120	CCCCGGCAAGGGCCTGGAGTGGGTGAGCTACATCAGCAGCAGCAGCGGCTTCGTGTACGC		179
CO	120	CCCTGGCAAGGGCCTGGAATGGGTGTCCTACATCAGCAGCAGCTCCGGCTTCGTGTACGC		179
Original	180	CGACAGCGTGAAGGGCAGGTTCAACCATCAGCAGGGACAACGCCCAGAACAGCCTGTACCT		239
CO	180	CGACAGCGTGAAGGGCCGGTTCACCATCAGCAGAGACAACGCCCAGAACAGCCTGTACCT		239
Original	240	GCAGATGAACAGCCTGAGGGCCGAGGACACCGCCGTGTACTACTGCGCCAGGAGCGAGGC		299
CO	240	GCAGATGAACTCCCTGCGGGCCGAGGACACCGCCGTGTACTACTGTGCCAGAAGCGAGGC		299
Original	300	CGCCTTCTGGGGCCAGGGCACCTGGTGACCGTG		333
CO	300	CGCCTTTTGGGGCCAGGGAACACTCGTGACAGTG		333

Fig. 6

hLC Alterations
Sequence was codon optimized for *homo sapiens*
89% homology to original sequence after codon optimization (CO)

VL

Sequence ID: Query_71369 Length: 336 Number of Matches: 1

Range 1: 1 to 336 Graphics				▼ Next Match ▲ Previous Match	
Score	Expect	Identities	Gaps	Strand	
411 bits(222)	2e-119	298/336(89%)	0/336(0%)	Plus/Plus	
Original	1	GACATCGTGCTGACCCAGAGCCCCCGCAGCCTGCCCGTGACCCCCGGCGAGCCCGCCAGC	60		
CO	1	GATATCGTGCTGACCCAGAGCCCCAGATCCCTGCCTGTGACACCTGGCGAGCCTGCCAGC	60		
Original	61	ATCAGCTGCAGGTCCCTCCAAGTCCAGGCTGAGCAGGATGGGCATCACCCCCCTGAACTGG	120		
CO	61	ATCAGCTGCAGAAGCAGCAAGAGCCGGCTGAGCCGGATGGGCATCACCCCCCTGAACTGG	120		
Original	121	TACCTGCAGAAGCCCCGGCCAGAGCCCCCAGCTGCTGATCTACAGGATGAGCAACAGGGCC	180		
CO	121	TATCTGCAGAAACCCGGCCAGTCCCCCAGCTGCTGATCTACCGGATGAGCAACAGAGCC	180		
Original	181	AGCGGCGTGCCCGACAGGTTTCCAGCGGCAGCGGCAGCGGCACCGACTTCACCCTGAAGATC	240		
CO	181	AGCGGCGTGCCCGATAGATTTTCCGGCTCTGGAAGCGGCACCGACTTCACCCTGAAGATC	240		
Original	241	AGCAAGGTGGAGACCGAGGACGTGGGCGTGTACTACTGCGCCCAGTTCCTGGAGTACCCC	300		
CO	241	AGCAAGGTGGAAACCGAGGACGTGGGCGTGTACTATTGCGCCCAGTTCCTGGAATACCCC	300		
Original	301	cccACCTTCGGCAGCGGCACCAAGCTGGAGATCAAG	336		
CO	301	CCCACCTTTGGCAGCGGCACCAAGCTGGAAATCAAG	336		

Fig. 7

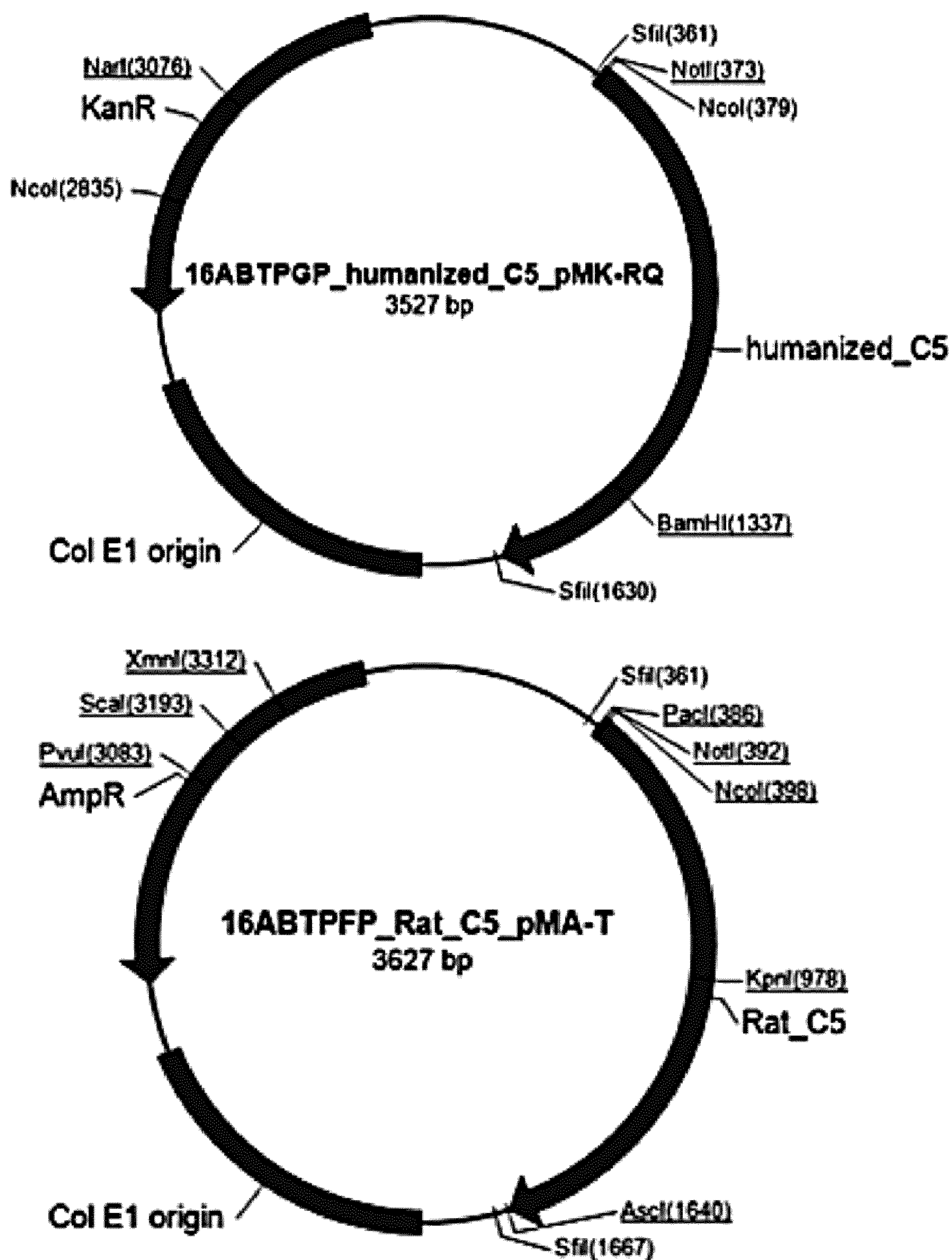


Fig. 7 (cont.)

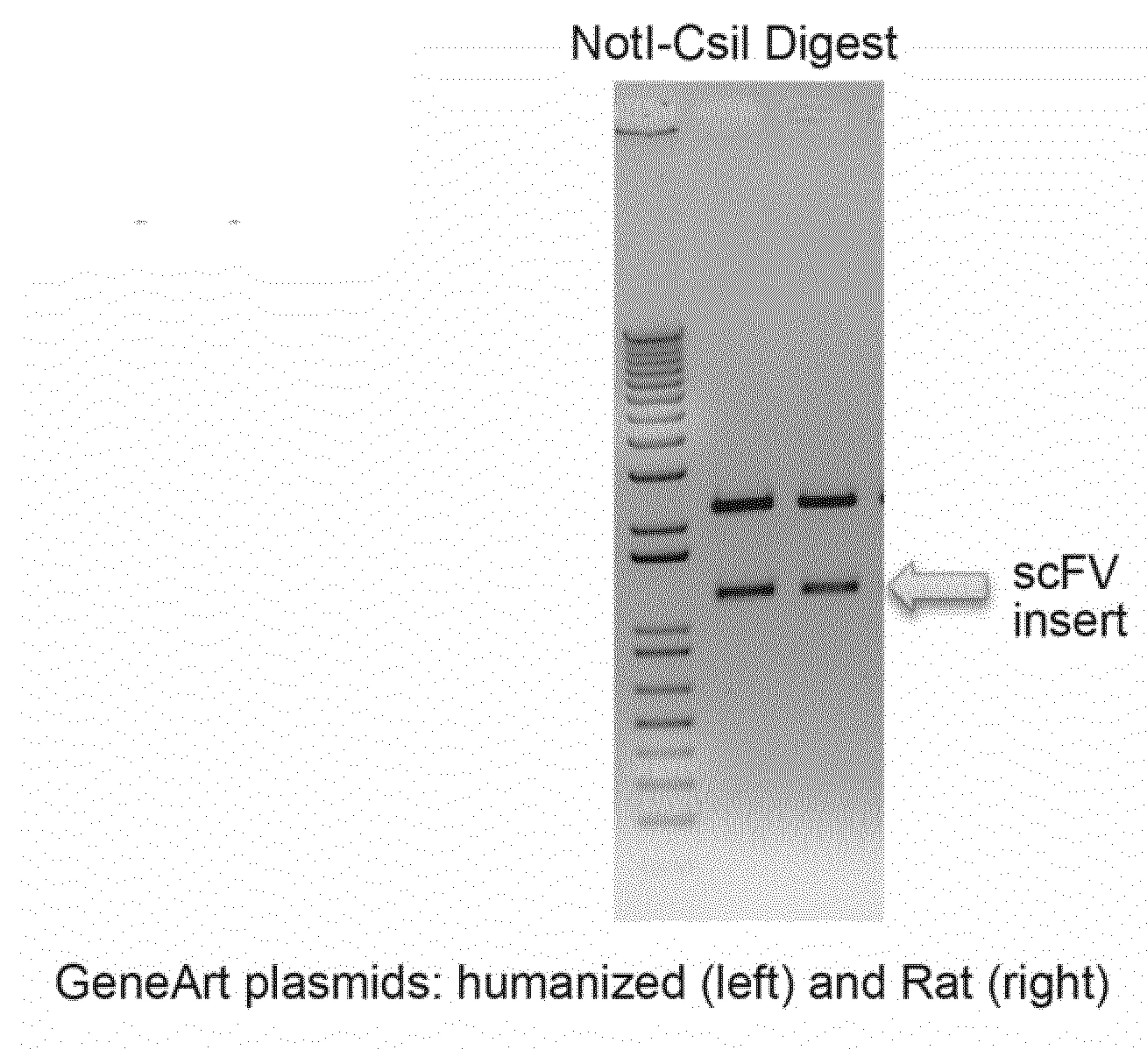


Fig. 8

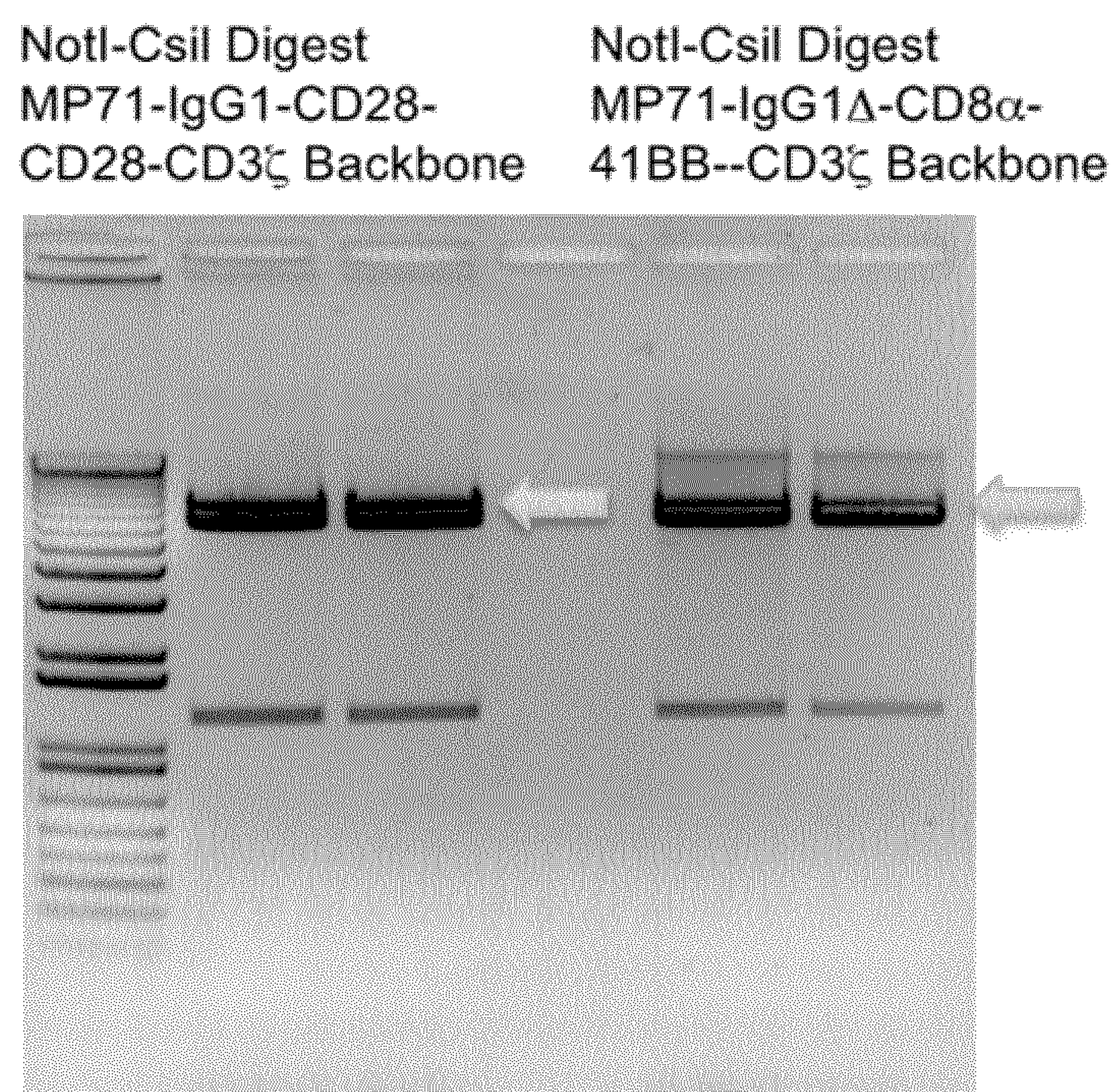


Fig. 8 (cont.)

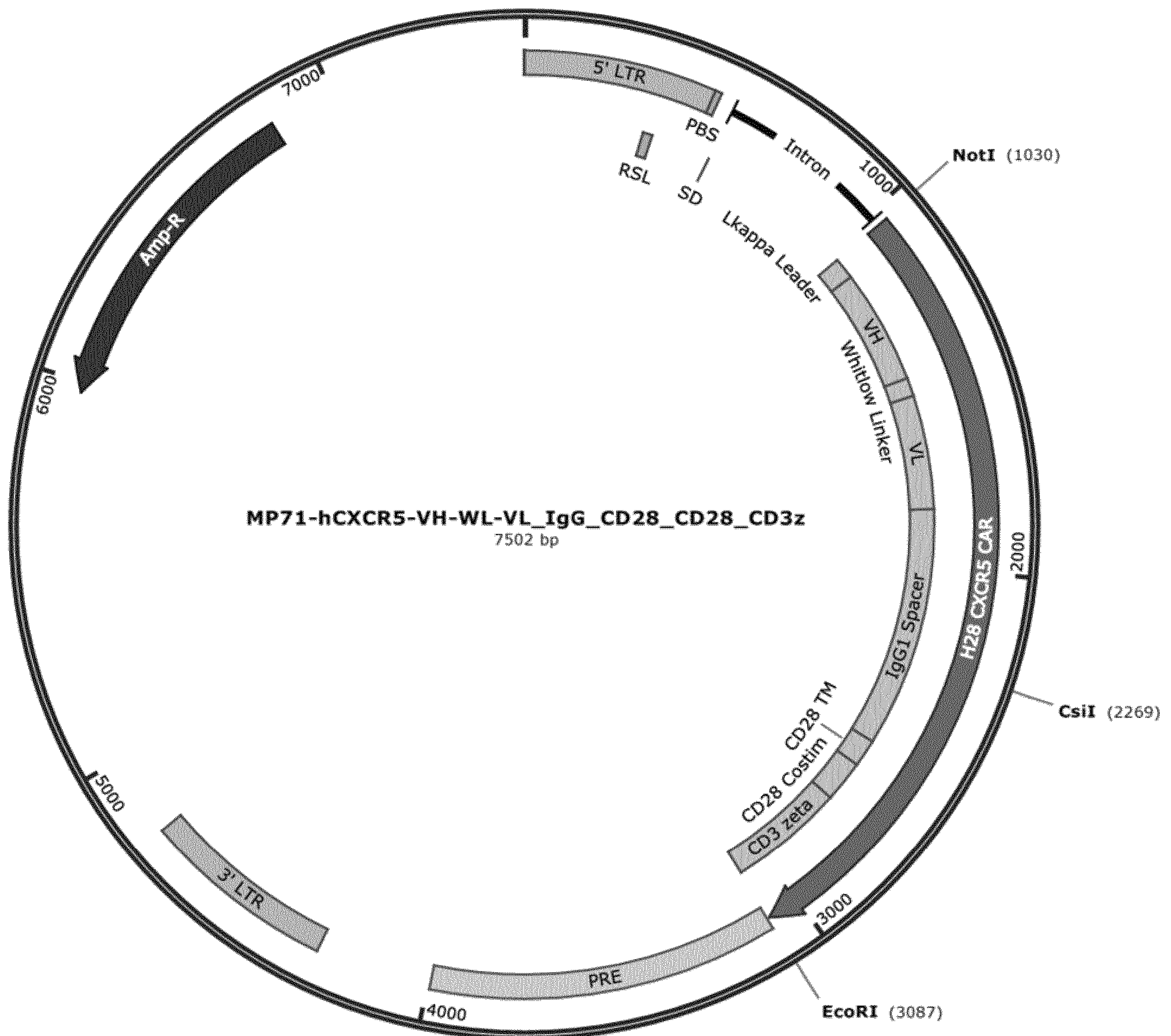


Fig. 9

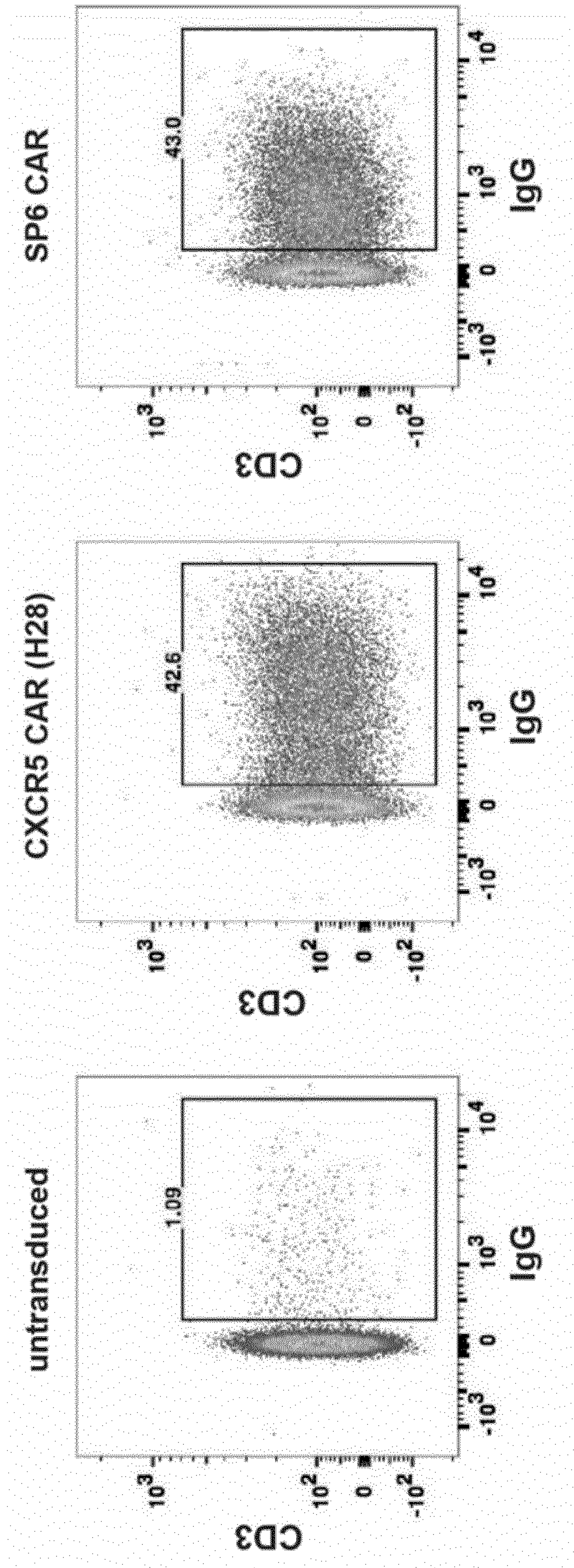


Fig. 10

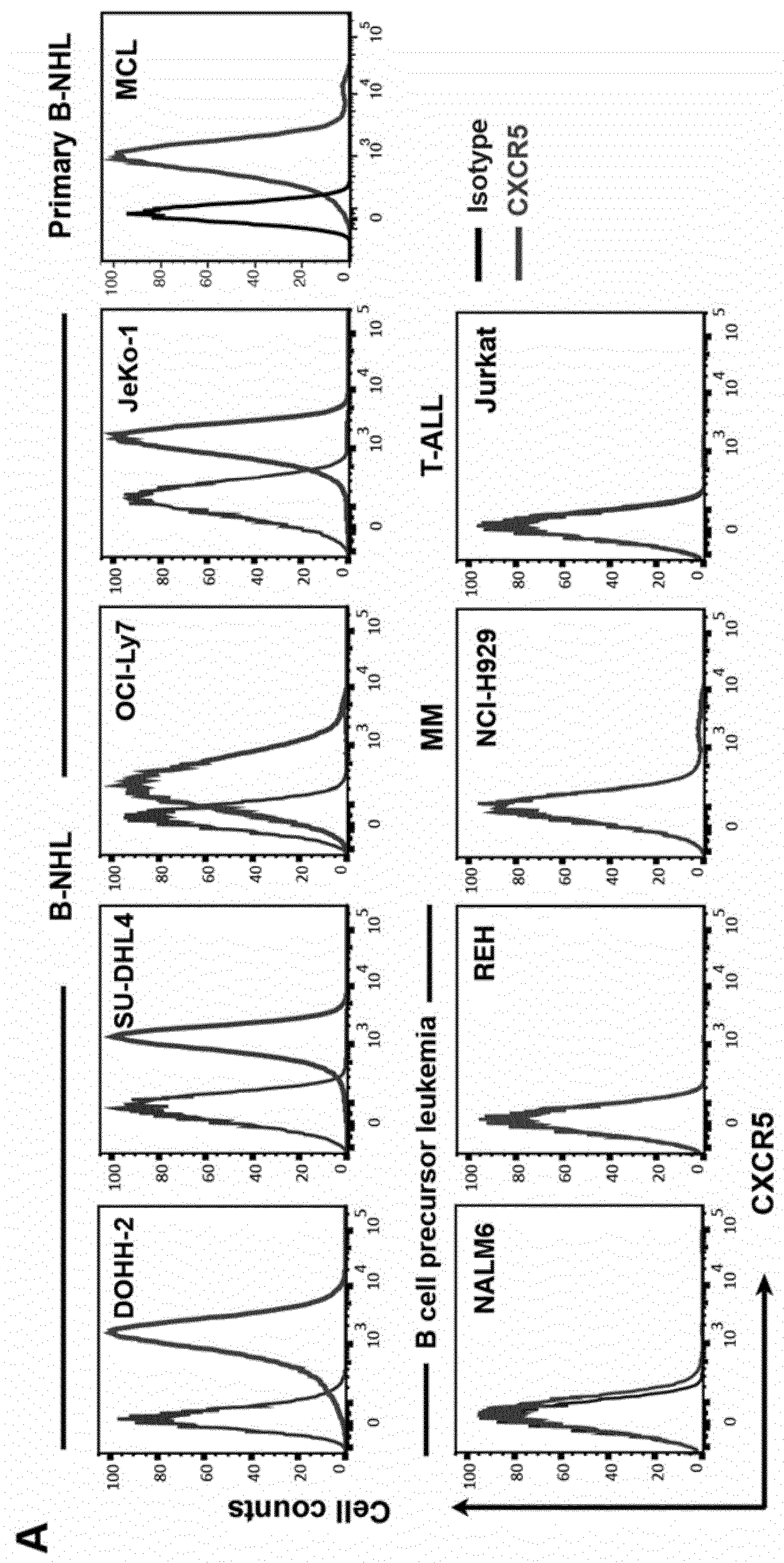


Fig. 10 (cont.)

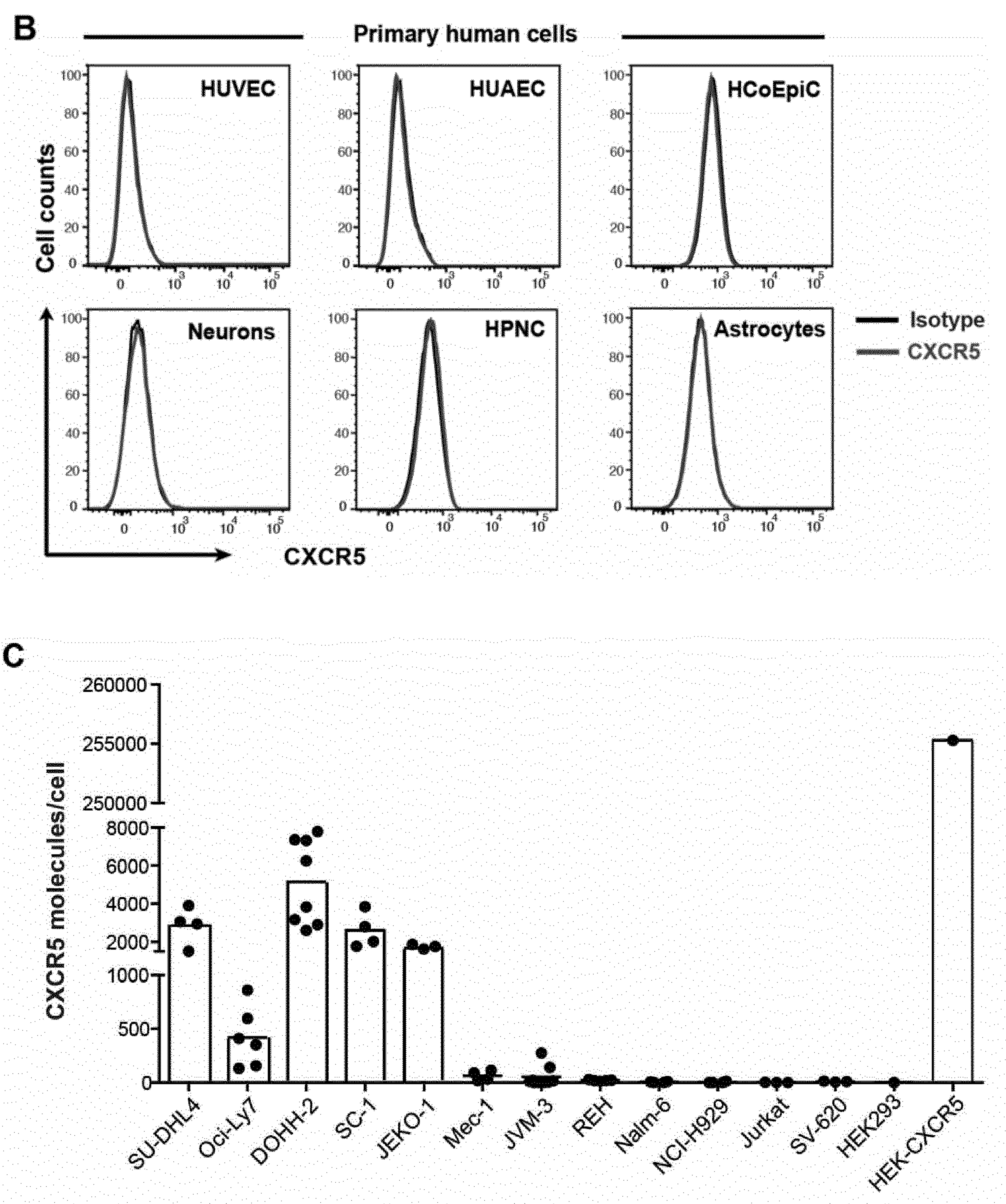


Fig. 11

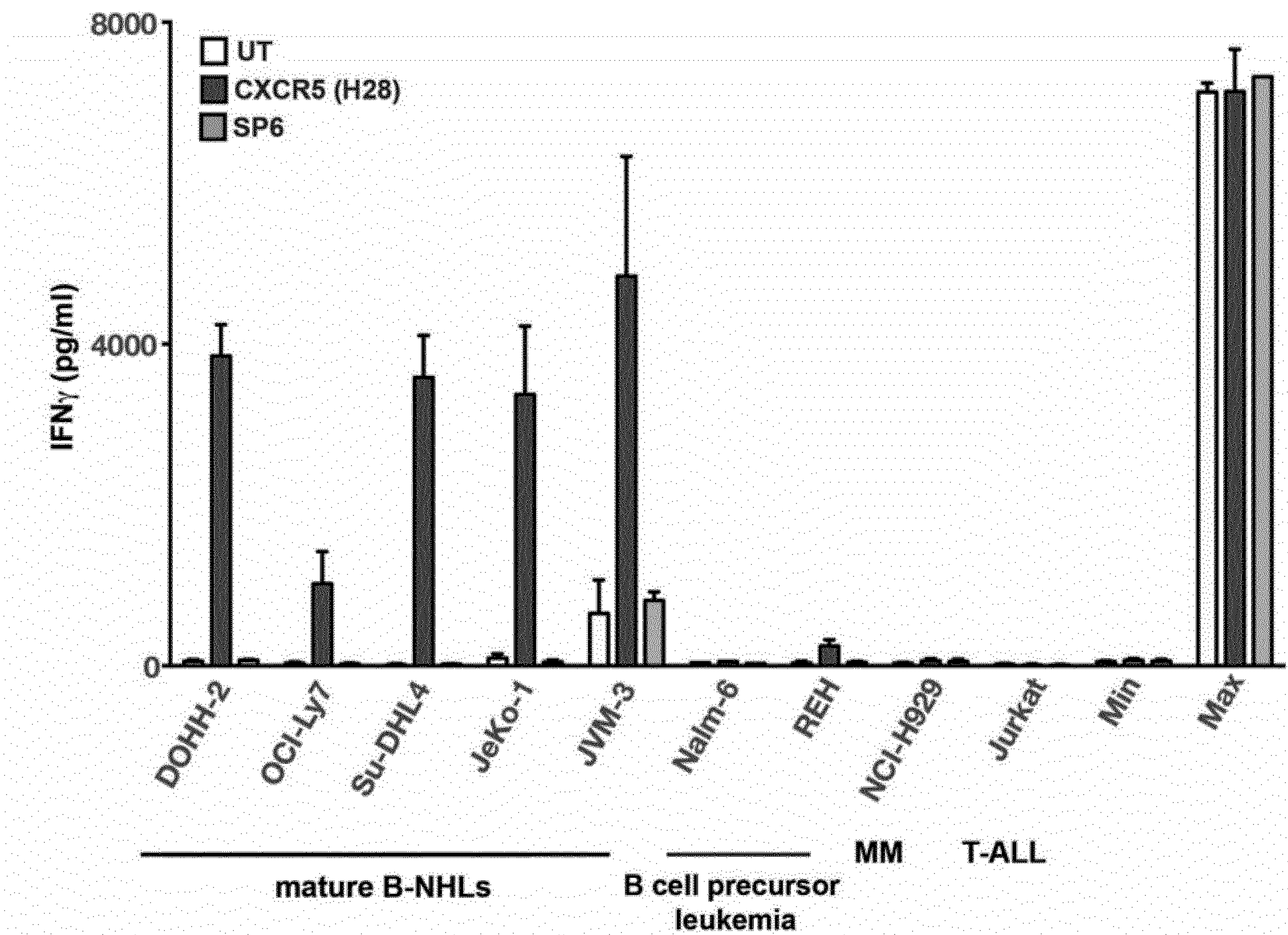


Fig. 12

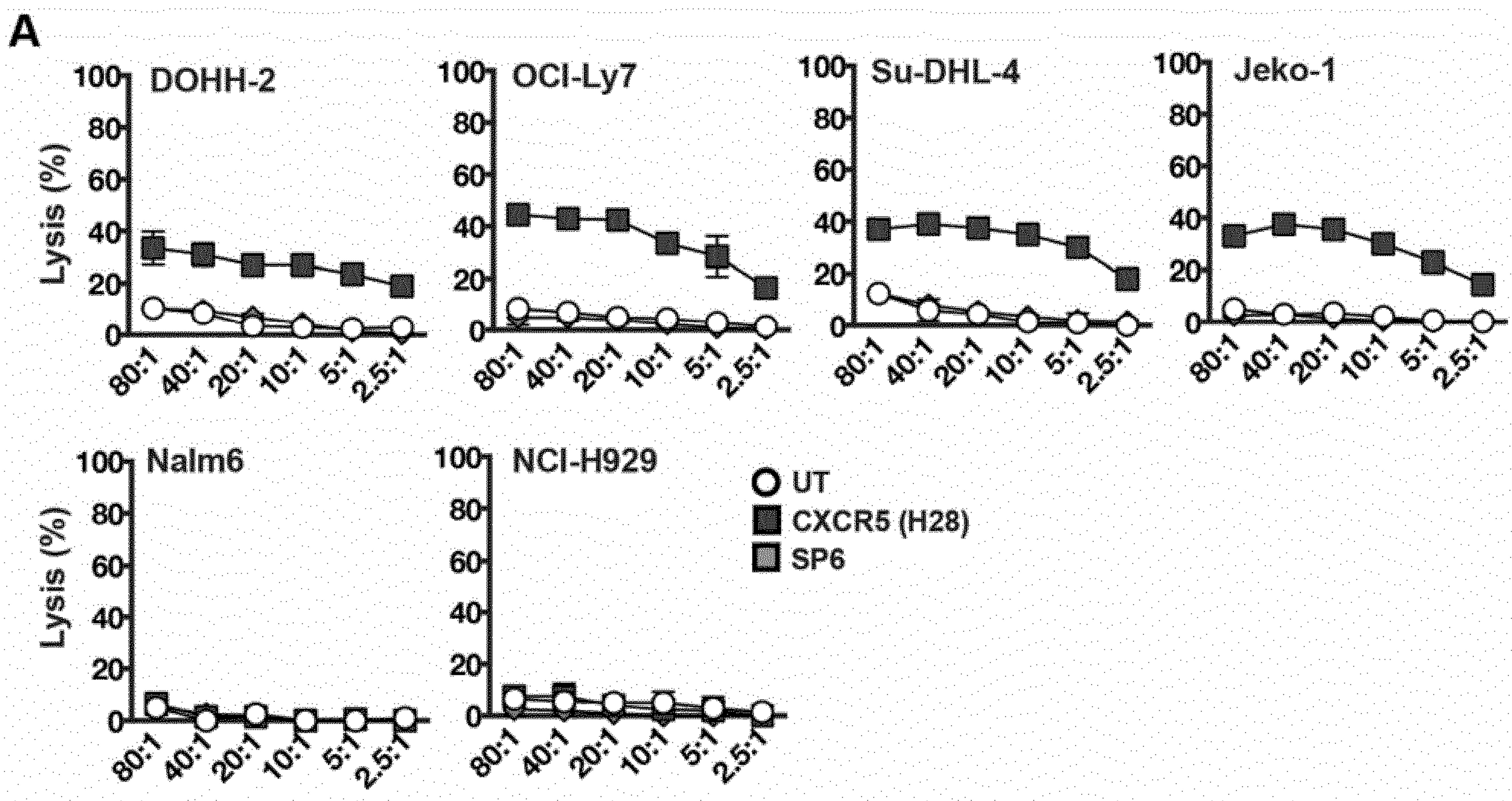


Fig. 12 (cont.)

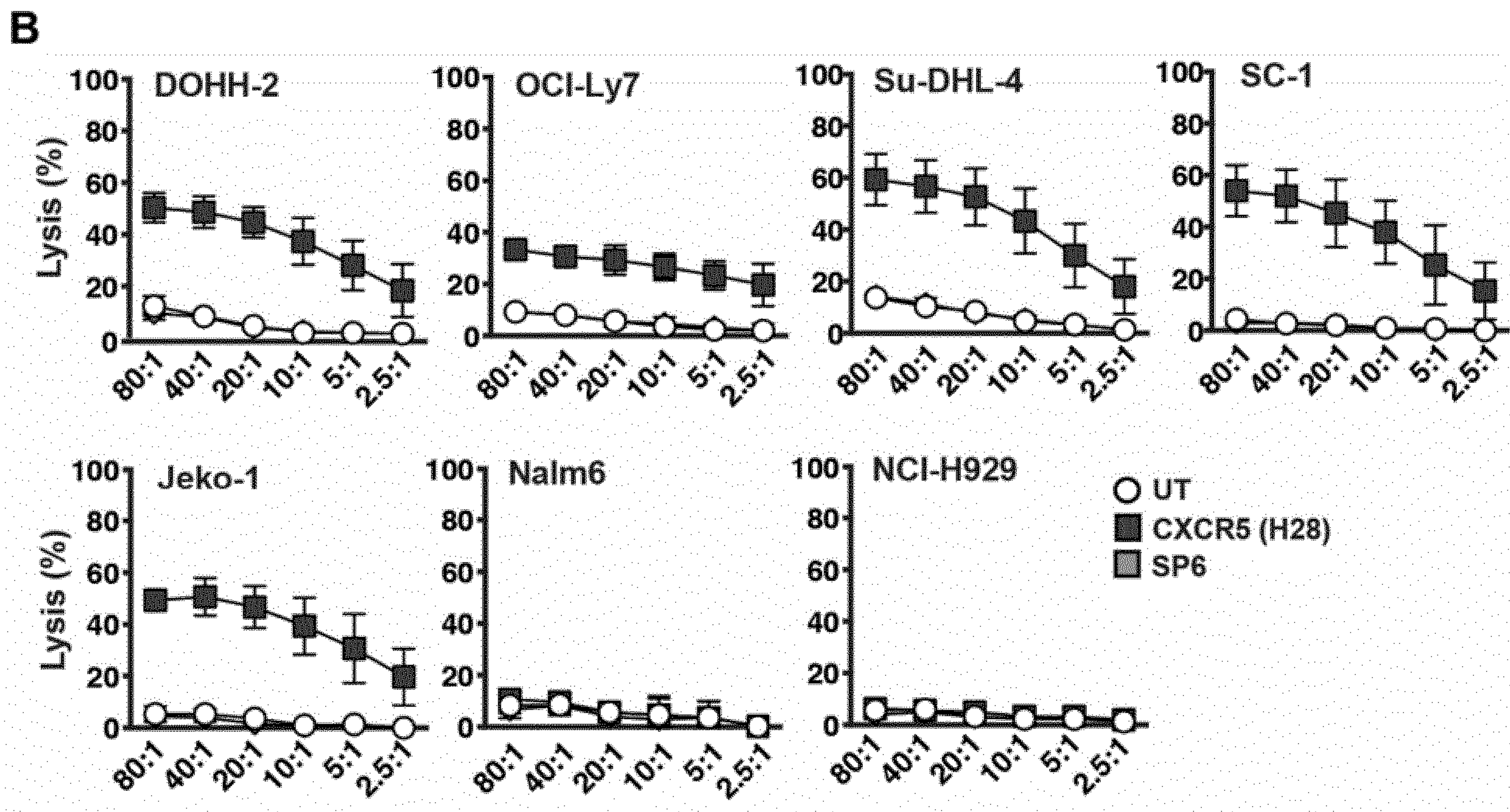


Fig. 13

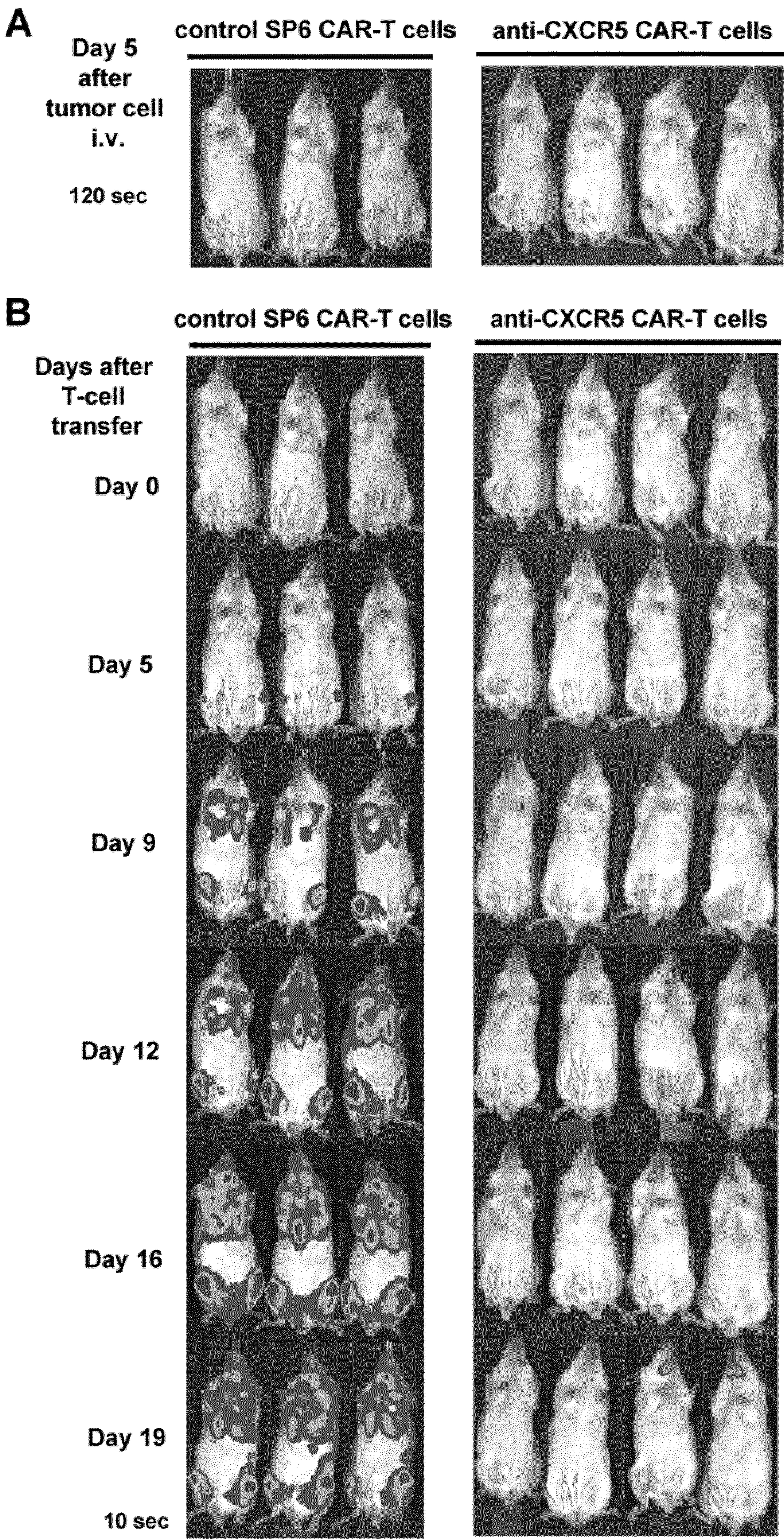


Fig. 13 (cont.)

C

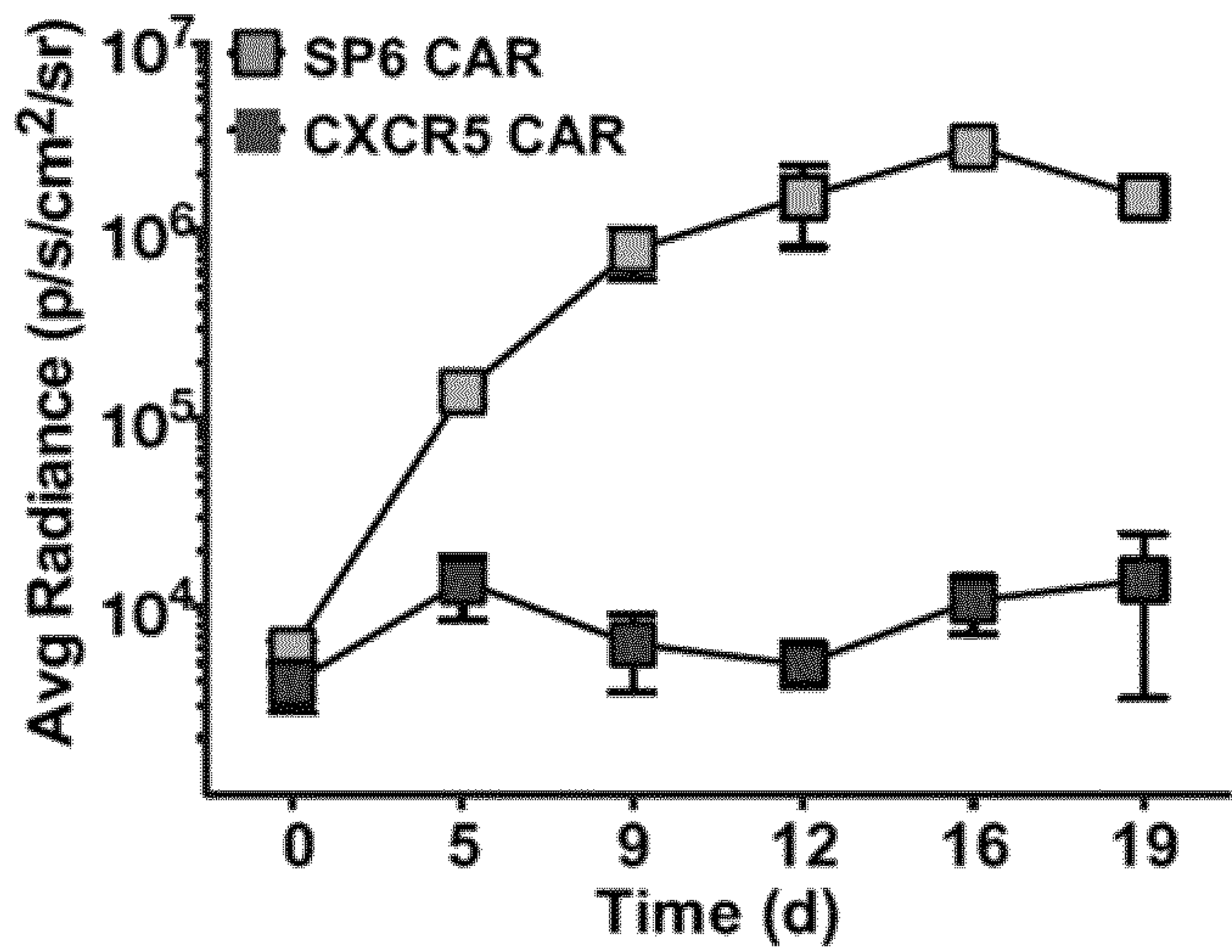


Fig. 14

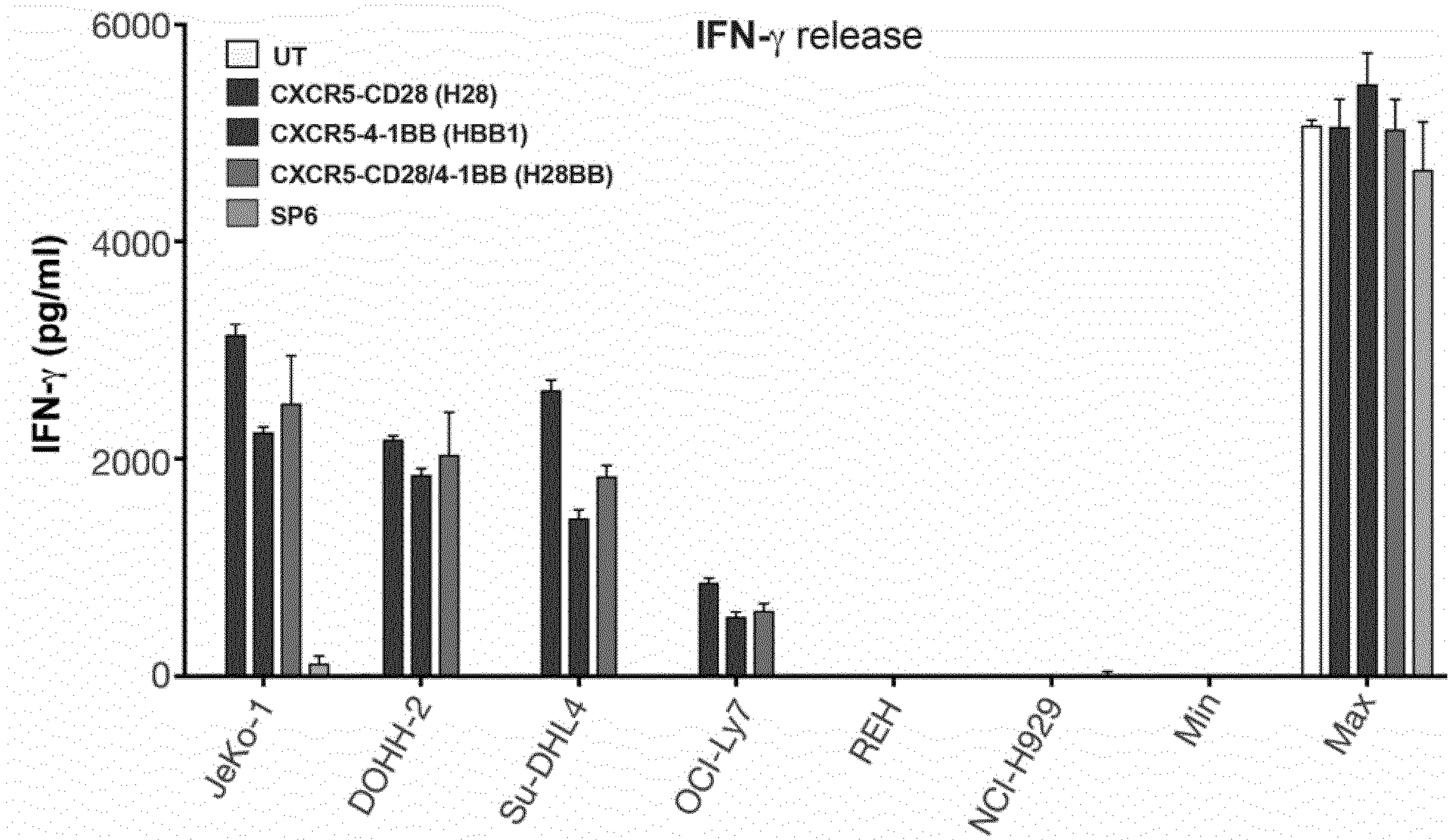


Fig. 14 (cont.)

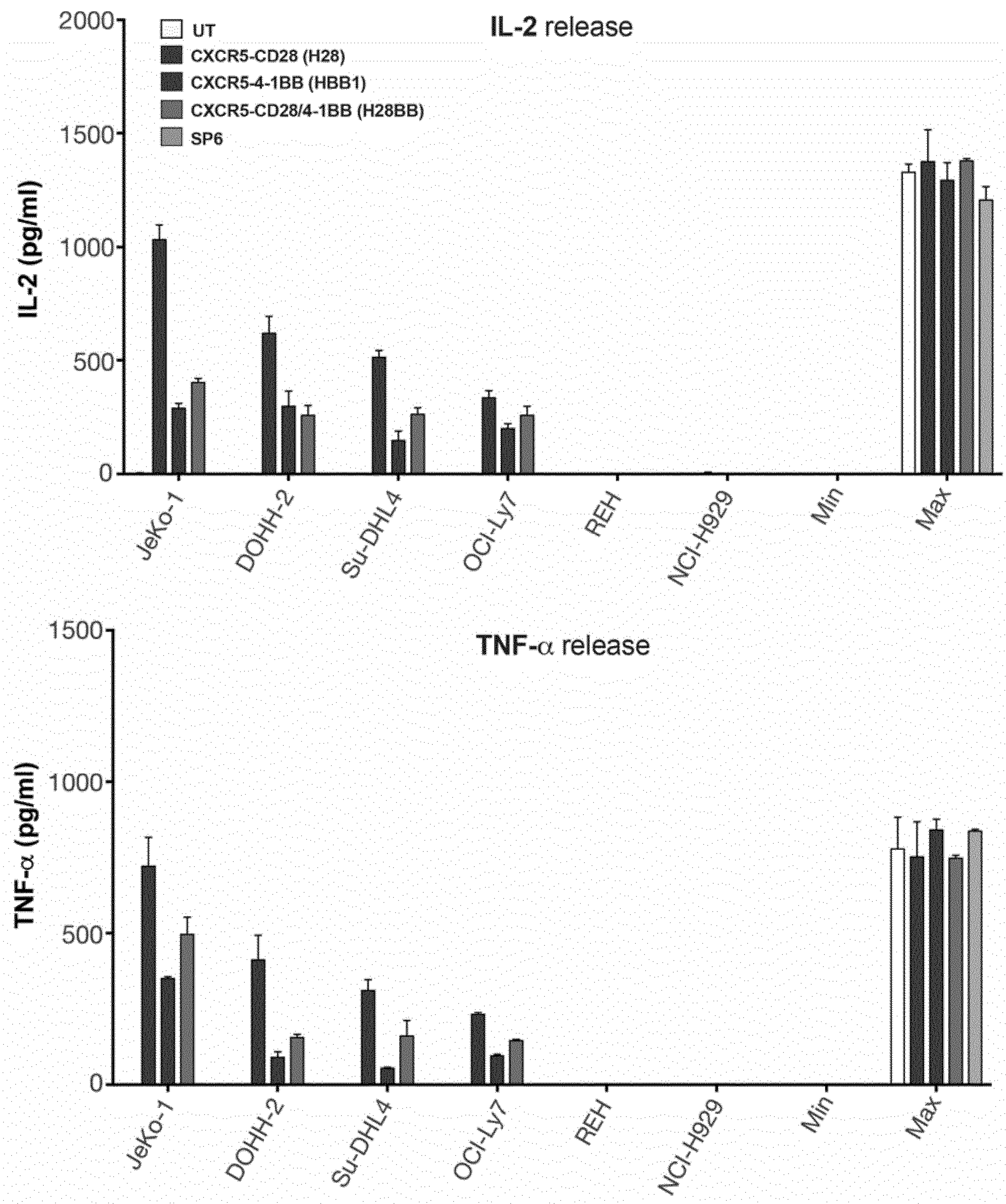


Fig. 15

