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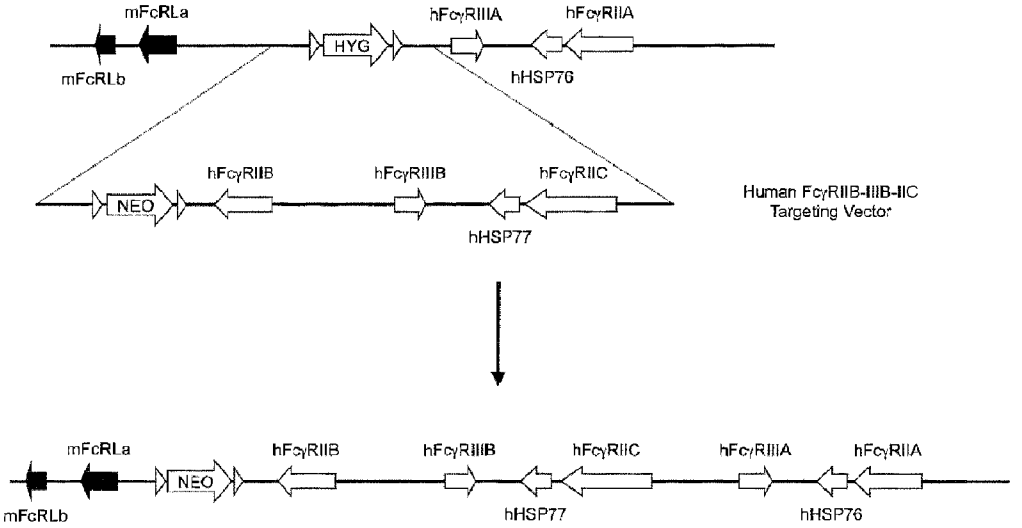

(57) Abrégé/Abstract:
Genetically modified non-human animals, specifically mice, and methods and compositions for making and using them are provided, wherein the genetic modification comprises replacing the endogenous low affinity FcγR α-chain genes with at least two low affinity human FcγR α-chain genes, wherein the endogenous low affinity FcγR α-chain genes are FcγRIIB, FcγRIII and FcγRIV and the at least two low affinity human FcγR α-chain genes are either human FcγRIIA and FcγRIIIA or human FcγRIIA, FcγRIIB, FcγRIIC, FcγRIIIA and FcγRIIIB, and wherein the mouse is capable of expressing a functional FcRγ-chain. Genetically modified mice are described, including mice that express low affinity human FcγR genes from the endogenous FcγR locus, and wherein the mice comprise a functional FcRγ-chain.

ABSTRACT

Genetically modified non-human animals, specifically mice, and methods and compositions for making and using them are provided, wherein the genetic modification comprises replacing the endogenous low affinity FcγR α-chain genes with at least two low affinity human FcγR α-chain genes, wherein the endogenous low affinity FcγR α-chain genes are FcγRIIB, FcγRIII and FcγRIV and the at least two low affinity human FcγR α-chain genes are either human FcγRIIA and FcγRIIIA or human FcγRIIA, FcγRIIB, FcγRIIC, FcγRIIIA and FcγRIIIB, and wherein the mouse is capable of expressing a functional FcRγ-chain. Genetically modified mice are described, including mice that express low affinity human FcγR genes from the endogenous FcγR locus, and wherein the mice comprise a functional FcRγ-chain.

HUMANIZED FcγR MICE

FIELD OF INVENTION

[0001] The field of invention is genetically modified non-human animals that lack endogenous murine FcγR genes, including genetically modified animals that comprise a replacement of endogenous FcγR genes with human FcγR genes, and including mice that are capable of expressing at least two, three, four, or five functional human low affinity FcγR genes, and including genetically modified mice comprising immune cells that do not express endogenous low affinity FcγR genes.

BACKGROUND

[0002] Fc receptors (FcRs) are proteins found on the surface of cells of the immune system that carry out a variety of functions of the immune system in mammals. FcRs exist in a variety of types, on a variety of cells, and mediate a variety of immune functions such as, for example, binding to antibodies that are attached to infected cells or invading pathogens, stimulating phagocytic or cytotoxic cells to destroy microbes, or infected cells by antibody-mediated phagocytosis or antibody-dependent cell-mediated cytotoxicity (ADCC).

[0003] ADCC is a process whereby effector cells of the immune system lyse a target cell bound by antibodies. This process depends on prior exposure to a foreign antigen or cell, resulting in an antibody response. ADCC can be mediated through effector cells such as, for example, natural killer (NK) cells, by binding of FcR expressed on the surface of the effector cell to the Fc portion of the antibody which itself is bound to the foreign antigen or cell. Because of the central role that FcRs play in the immune response, useful non-human animals that co-express multiple human FcRs are needed, including non-human animals that co-express multiple human low affinity FcRs. There exists a need for non-human animal models of human FcR function and human processes of ADCC for the study and elucidation of human disease therapies, in particular anti-tumor therapies and therapies for treating autoimmune diseases, and pharmaceutical drug development, in particular in the development, design, and testing of human antibody pharmaceuticals.

BRIEF DESCRIPTION OF THE FIGURES

[0004] Figure 1 is a schematic depiction of a wild type low affinity FcγR locus in a mouse, showing mouse FcγRIIB, FcγRIV and FcγRIII genes and a mouse FcγR targeting vector used for a targeted deletion of these genes, which includes a neomycin cassette flanked by site-specific recombination sites.

[0005] Figure 2 shows histograms of splenocytes gated for B cells (anti-CD19), NK cells (anti-NKp46) and macrophages (anti-F4/80) including expression of endogenous mFcγRII and mFcγRIII genes for wild type and low affinity FcγR α-chain gene-deficient mice (mFcγR KO).

[0006] Figures 3A-3D show *in vivo* depletion of B cells with a human anti-human CD20 antibody with mouse Fc (Ab 168) or human Fc (Ab 735) in humanized CD20 mice (hCD20) and humanized CD20 mice bred to FcγR knockout mice (hCD20/FcγR KO) in several lymphocyte compartments: bone marrow (Figure 3A), blood (Figure 3B), lymph node (Figure 3C) and spleen (Figure 3D). For each graph, the y-axis shows the percent of gated B cells ($B220^+/IgM^+$ or $B220^+/CD19^+$) and the x-axis shows the antibody dose for each animal group: 10 mg/kg Control antibody (C), 2 mg/kg human anti-human CD20 antibody (2 Ab) and 10 mg/kg human anti-human CD20 antibody (10 Ab).

[0007] Figure 4 is a schematic depiction of a neomycin-targeted deletion of the low-affinity mouse FcγR locus and a second targeting vector for inserting two human low affinity FcγR genes (hFcγRIIIA and hFcγRIIA) into the deleted mouse locus, which includes a hygromycin cassette flanked by site-specific recombination sites. For expression of hFcγRIIA on platelets, an extended promoter region operably linked to the hFcγRIIA gene of the Human FcγRIIIA-IIA Targeting Vector is employed; to prevent expression of hFcγRIIA on platelets, the promoter region is omitted or substantially omitted.

[0008] Figure 5A shows histograms of splenocytes gated for NK cells (anti-NKp46) and macrophages (anti-F4/80) including expression of human FcγRIIIA for wild type and human FcγRIIIA-IIA homozygote mice (Human FcγRIIIA/FcγRIIA HO).

[0009] Figure 5B shows histograms of splenocytes gated for neutrophils (anti-Ly6G) and macrophages (anti-F4/80) including expression of human FcγRIIA for wild type and human FcγRIIIA-IIA homozygote mice (Human FcγRIIIA/FcγRIIA HO).

[0010] Figure 6 is a schematic depiction of a hygromycin-targeted deletion of the low affinity mouse FcγR locus including an insertion of two low affinity human FcγR genes (hFcγRIIIA and hFcγRIIA) and a third targeting vector for inserting three additional low affinity human FcγR

genes (hFcγRIIB, hFcγRIIIB and hFcγRIIC) and a neomycin cassette flanked by site-specific recombination sites.

[0011] Figure 7 shows histograms of splenocytes gated for B cells (anti-CD19) and neutrophils (anti-Ly6G) including expression of human FcγRIIB and human FcγRIIIB for wild type and human FcγRIIIA-IIIB-IIA-IIB-IIC homozygote mice (Human FcγRIIIA/FcγRIIIB/FcγRIIA/FcγRIIB/FcγRIIC HO).

SUMMARY

[0012] Genetically modified cells, non-human embryos, non-human animals and methods and compositions for making and using them are provided. In various aspects, the non-human animals comprise a human FcγR receptor, a deletion of an endogenous low affinity FcγR receptor, and/or a replacement of an endogenous FcγR receptor with a human FcγR receptor at an endogenous mouse low affinity FcγR locus.

[0013] In one aspect, genetically modified cells, non-human embryos, and non-human animals are provided that comprise a functional FcR γ–chain, wherein the cells, embryos, and animals comprise a further modification comprising a replacement of the low affinity endogenous non-human FcγR gene sequences (*e.g.*, FcγRIIB, FcγRIV and FcγRIII) with one or more low affinity human FcγR gene sequences (*e.g.*, selected from FcγRIIA, FcγRIIB, FcγRIIC, FcγRIIIA, FcγRIIIB, and a combination thereof).

[0014] In one embodiment, the cells, non-human embryos, and non-human animals are murine. In one embodiment, the functional FcR γ-chain is a mouse FcR γ-chain. In one embodiment, the mouse FcR γ-chain is an FcR γ-chain endogenous to the mouse, the cell, or the embryo.

[0015] In one embodiment, the cells, embryos, and animals are mice, and the mice express a functional α-chain of a human low affinity FcγR receptor and a functional endogenous mouse γ-chain.

[0016] In one aspect, a genetically modified mouse is provided, wherein the mouse does not express an endogenous α-chain selected from an FcγRIIB α-chain, an FcγRIV α-chain, an FcγRIII α-chain, and a combination thereof; wherein the mouse expresses a functional endogenous mouse γ-chain.

[0017] In a specific embodiment, the mouse does not express a functional FcγRIIB α-chain, does not express a functional FcγRIV α-chain, and does not express a functional FcγRIII α-chain.

[0018] In one embodiment, the mouse genome comprises a deletion of an endogenous FcγRIIB α-chain, a deletion of an endogenous FcγRIV α-chain, and a deletion of an endogenous FcγRIII α-chain.

[0019] In one embodiment, the mouse comprises a deletion of an endogenous FcγRIIB α-chain, a deletion of an endogenous FcγRIV α-chain, and a deletion of an endogenous FcγRIII α-chain, and further comprises a reduced ability to make an immune response to an antigen as compared with a wild type mouse's ability with respect to the same antigen. In one embodiment, the reduced immune response includes a decreased antibody-dependent cell-mediated cytotoxicity (ADCC). In one embodiment, the reduced immune response includes a reduced ability in a cell killing assay to achieve antibody-dependent NK cell killing. In specific embodiments, the reduction in ADCC or antibody-dependent NK cell killing is at least 50%, in one embodiment at least 75%, in one embodiment at least 90%.

[0020] In one embodiment, the mouse comprises a deletion of an endogenous FcγRIIB α-chain, a deletion of an endogenous FcγRIV α-chain, and a deletion of an endogenous FcγRIII α-chain, and further comprises an increased humoral antibody response upon immunization with an antigen as compared to a wild type mouse, *e.g.*, a mouse of the same or similar strain that does not comprise the deletion. In one embodiment, the increased humoral antibody response is 2-fold as compared to a wild type mouse. In one embodiment, the increased humoral antibody response is 3-fold as compared to a wild type mouse. In one embodiment, the increased humoral antibody response is 5-fold as compared to a wild type mouse. In one embodiment, the increased humoral antibody response is 7-fold as compared to a wild type mouse. In one embodiment, the increased humoral antibody response is 10-fold as compared to a wild type mouse. In a specific embodiment, humoral antibody response is measured by micrograms of antibody that specifically binds an antigen (with which the mouse has been immunized) per microgram of serum protein from the mouse. In one embodiment, the increased humoral antibody response is with respect to an antigen to which a wild type mouse exhibits tolerance, or to an antigen which in a wild type mouse exhibits a poor or minimal humoral immune response. In a specific embodiment, the antigen is a mouse antigen. In a

specific embodiment, the antigen is a human antigen that exhibits an identity with a mouse protein of at least about 95%, 96%, 97%, 98%, or 99%.

[0021] In one aspect, a genetically modified mouse is provided, comprising a replacement of a low affinity mouse FcγR α-chain gene with a low affinity human FcγR α-chain gene, wherein the replacement is at the endogenous mouse FcγR α-chain gene locus. In one embodiment, the low affinity mouse FcγR α-chain gene is selected from an FcγRIIB, FcγRIV and an FcγRIII α-chain gene. In a specific embodiment, a genetically modified mouse is provided, wherein the mouse expresses an endogenous FcR γ-chain, and wherein the low affinity human FcγR α-chain gene is FcγRIIIA α-chain. In another specific embodiment, the genetically modified mouse expresses an endogenous FcR γ-chain and a functional human FcγRIIIA α-chain on NK cells. In a specific embodiment, the functionality of FcγRIIIA α-chain on NK cells is reflected by human antibody-mediated NK killing (*e.g.*, ADCC mediated by a human antibody).

[0022] In one aspect, a genetically modified cell, non-human embryo, or non-human animal is provided, wherein the genetic modification comprises a replacement of at least one endogenous low affinity FcγR α-chain gene with a human FcγR α-chain gene, and the cell, embryo, or animal expresses a functional FcR γ-chain. In one embodiment, the functional FcRγ-chain is an endogenous FcR γ-chain. In one embodiment, the low affinity human FcγR α-chain gene is selected from an FcγRIIA α-chain gene, an FcγRIIIA α-chain gene, and a combination thereof. In a specific embodiment, the human FcγRIIA gene comprises a polymorphism, wherein the polymorphism is selected from a 131His low responder polymorphism and a 131Arg high responder polymorphism. In a specific embodiment, the FcγRIIA polymorphism is the 131His low responder polymorphism. In one embodiment, the FcγRIIIA gene is a specific allelic variant, wherein the allelic variant is selected from a 158Val variant and a 158Phe variant. In a specific embodiment, the FcγRIIIA allelic variant is the 158Val variant.

[0023] In one embodiment the low affinity human FcγR gene is selected from an FcγRIIB, FcγRIIC, an FcγRIIIB gene, and a combination thereof. In a specific embodiment, the human FcγRIIB gene comprises an amino acid substitution, wherein the substitution is selected from an 232Ile or a 232Thr substitution. In another specific embodiment, amino acid substitution is a 232Ile substitution. In a specific embodiment, the FcγRIIIB gene is a specific allelic variant, wherein the allelic variant is selected from a NA1 variant and a NA2 variant. In another specific embodiment, the FcγRIIIB allelic variant is a NA2 variant.

[0024] In one embodiment the low-affinity human FcγR α-chain gene is selected from a FcγRIIA, FcγRIIB, FcγRIIC, FcγRIIIA, FcγRIIIB α-chain gene, and a combination thereof.

[0025] In one embodiment, the low affinity mouse FcγRIV α-chain gene and the FcγRIII α-chain gene are replaced with at least one low affinity human FcγR α-chain gene. In one embodiment, the low affinity mouse FcγRIV α-chain gene and the FcγRIIB α-chain gene are replaced with at least one low affinity human FcγR α-chain gene. In one embodiment, the low affinity mouse FcγRIIB α-chain gene and the FcγRIII α-chain gene are replaced with at least one low affinity human FcγR α-chain gene. In a specific embodiment, the at least one low affinity human FcγR α-chain gene is selected from an FcγRIIA, FcγRIIB, FcγRIIC, FcγRIIIA , FcγRIIIB α-chain gene, and a combination thereof. In another specific embodiment, the at least one low affinity human FcγR α-chain gene is selected from an FcγRIIA α-chain gene, an FcγRIIIA α-chain gene, and a combination thereof. In another specific embodiment, the at least one low affinity human FcγR α-chain gene is selected from an FcγRIIB, FcγRIIC, FcγRIIIB α-chain gene, and a combination thereof. In another specific embodiment, the low affinity mouse FcγR genes are replaced with a human FcγRIIA α-chain gene and a human FcγRIIIA α-chain gene. In another specific embodiment, the low affinity human FcγRIIA and FcγRIIIA α-chain genes comprise variants, wherein the FcγRIIA α-chain gene comprises a 131His variant and the FcγRIIIA α-chain gene comprises a 158Val variant. In another specific embodiment, the low affinity mouse FcγR α-chain genes are replaced with the following low affinity human FcγR α-chain genes: FcγRIIB, FcγRIIC and FcγRIIIB. In another specific embodiment, the low affinity human FcγRIIB α-chain gene and FcγRIIIB α-chain gene comprise variants, wherein the FcγRIIB α-chain gene comprises a 232Ile variant and the FcγRIIIB α-chain gene comprises an NA2 variant.

[0026] In one embodiment, the genetic modifications comprise a replacement of syntenic genomic sequences of mouse and human chromosome 1. In a specific embodiment, the genetic modifications comprise a replacement of a genomic fragment comprising endogenous low affinity mouse FcγR genes with a genomic fragment comprising low affinity human FcγR genes. In another specific embodiment, the mouse genome from chromosome 1:172,889,983 to chromosome1:172,989,911 is replaced with a human genomic fragment comprising human chromosome 1:161,474,729 to chromosome1:161,620,458.

[0027] In one aspect, a genetically modified cell, non-human embryo, or non-human animal is provided, wherein the genetic modification comprises a knockout of one or more endogenous low affinity receptor α-chain genes, and the presence of an episome comprising one or more human FcγR α-chain genes. In a specific embodiment, the cell, embryo, or animal expresses a functional FcR γ-chain. In a specific embodiment, the episome is a mini chromosome. In one embodiment, the functional FcR γ-chain is endogenous to the cell, embryo, or animal.

[0028] In one aspect, a genetically modified mouse is provided, comprising a replacement of a low affinity mouse FcγR α-chain gene with a low affinity human FcγR α-chain gene, the mouse comprises a mouse FcRγ-chain gene, and the mouse expresses a functional human low affinity FcγR receptor. In one embodiment, the functional low affinity FcγR receptor is expressed on a cell type in which the low affinity FcγR receptor is expressed in humans. In a specific embodiment, the functional human low affinity FcγR receptor is FcγRIIIA and the FcγRIIIA is expressed on NK cells.

[0029] In one embodiment, the mouse comprises a deletion of two mouse FcγR α-chain genes. In another embodiment, the mouse comprises a deletion of three mouse FcγR α-chain genes.

[0030] In one embodiment, the mouse comprises a replacement of three mouse FcγR α-chain genes with at least one human FcγR α-chain gene. In another embodiment, the mouse comprises a replacement of two mouse FcγR α-chain genes with at least one human FcγR α-chain gene. In a specific embodiment, the mouse comprises a replacement of three mouse FcγR α-chain genes with at least two human FcγR α-chain genes. In another specific embodiment, the three mouse FcγR α-chain genes are replaced with three human FcγR α-chain genes. In another specific embodiment, the mouse comprises a replacement of two mouse FcγR α-chain genes with at least two human FcγR α-chain genes. In yet another specific embodiment, the two mouse FcγR α-chain genes are replaced with at least three human FcγR α-chain genes.

[0031] In one embodiment, the low affinity mouse FcγR α-chain gene is selected from an FcγRIIB, FcγRIV, FcγRIII α-chain gene, and a combination thereof.

[0032] In one embodiment, the low affinity human FcγR α-chain gene is selected from an FcγRIIA, FcγRIIB, FcγRIIC, FcγRIIIA, FcγRIIIB α-chain gene, and a combination thereof. In one embodiment, the low affinity human FcγR α-chain gene is selected from an FcγRIIA, an

FcγRIIIA α-chain gene, and a combination thereof. In one embodiment, the low affinity human FcγR α-chain gene is selected from an FcγRIIB, FcγRIIC, an FcγRIIIB α-chain gene, and a combination thereof.

[0033] In one embodiment, the low affinity mouse FcγRIV α-chain gene and the FcγRIII α-chain gene are replaced with at least one human FcγR α-chain gene. In one embodiment, the low-affinity mouse FcγRIV α-chain gene and the FcγRIIB α-chain gene are replaced with at least one human FcγR α-chain gene. In one embodiment, the low affinity mouse FcγRIIB α-chain gene and the FcγRIIIB α-chain gene are replaced with at least one human FcγR α-chain gene. In a specific embodiment, the at least one human FcγR α-chain gene is selected from an FcγRIIA, FcγRIIB, FcγRIIC, FcγRIIIA, FcγRIIIB α-chain gene, and a combination thereof. In another specific embodiment, the at least one human FcγR α-chain gene is selected from an FcγRIIA, an FcγRIIIA α-chain gene, and a combination thereof. In another specific embodiment, the at least one human FcγR α-chain gene is selected from an FcγRIIB, FcγRIIC, FcγRIIIB α-chain gene, and a combination thereof. In another specific embodiment, the mouse α-chain genes are replaced with the following human FcγR α-chain genes: FcγRIIA and FcγRIIIA. In yet another specific embodiment, the mouse α-chain genes are replaced with the following human FcγR α-chain genes: FcγRIIB, FcγRIIC and FcγRIIIB.

[0034] In one aspect, a genetically modified mouse is provided, comprising a low affinity human FcγR α-chain and a mouse FcR γ-chain subunit, wherein the mouse expresses the human FcγR α-chain on a cell selected from a neutrophil, an eosinophil, a basophil, a monocyte, a macrophage, a platelet, a Langerhans cell, a dendritic cell, an NK cell, a mast cell, a B cell, a T cell, and a combination thereof. In one embodiment, the mouse expresses a human FcγRIIA α-chain on a cell selected from a neturophil, a macrophage, an eosinophil, a platelet, a dendritic cell, a Langerhans cell, and a combination thereof. In one embodiment, the mouse is capable of phagocytosis, ADCC and cellular activation initiated or mediated through the expressed human FcγRIIA α-chain. In one embodiment the mouse expresses a human FcγRIIIA α-chain on a cell selected from a macrophage, an NK cell, a monocyte, a mast cell, an eosinophil, a dendritic cell, a Langerhans cell, at least one T cell type, and a combination thereof. In one embodiment, the mouse is capable of ADCC mediated through the human FcγRIIIA α-chain expressed on NK cells. In a specific embodiment, the mouse exhibits hFcγRIIIA-mediated ADCC in response to an antibody comprising a human Fc.

[0035] In one embodiment, the mouse expresses both a human FcγRIIA α-chain and a human FcγRIIIA α-chain. In one embodiment, the human FcγRIIA α-chain is expressed on platelets and the human FcγRIIIA α-chain is expressed on NK cells. In one embodiment, the mouse is capable of ADCC mediated by an antibody comprising a human Fc, wherein the mediation is through either the human FcγRIIA α-chain or through the human FcγRIIIA α-chain expressed on the surface of accessory cells. In one embodiment, the human FcγRIIA α-chain is not expressed on platelets. In a specific embodiment wherein the human FcγRIIA α-chain is not expressed on platelets, the mouse lacks or substantially lacks a human promoter sequence that operably linked to the human FcγRIIA α-chain in a human genome.

[0036] In one embodiment, the mouse expresses a human FcγRIIB α-chain on a cell selected from a B cell, a mast cell, a basophil, a macrophage, an eosinophil, a neutrophil, a dendritic cell, a Langerhans cell, and a combination thereof. In a specific embodiment, the mouse expresses a human FcγRIIB α-chain on a B cell and a mast cell. In another specific embodiment, the mouse is capable of endocytosis of immune complexes mediated through the expressed human FcγRIIB α-chain. In one embodiment, the mouse expresses a human FcγRIIC α-chain on a cell selected from a neutrophil, a macrophage, an eosinophil, a platelet, a dendritic cell, a Langerhans cell, and a combination thereof. In a specific embodiment, the mouse is capable of phagocytosis, ADCC and cellular activation initiated through the expressed human FcγRIIC α-chain.

[0037] In one embodiment, the mouse expresses a human FcγRIIIB α-chain on neutrophils and eosinophils. In a specific embodiment, the mouse is capable of cellular activation, phagocytosis, ADCC and degranulation, wherein the activation, phagocytosis, ADCC, and degranulation are mediated through the expressed human FcγRIIIB α-chain.

[0038] In one aspect, a mouse is provided that comprises a deletion of the endogenous FcγRIIB, FcγRIV and FcγRIII genes and insertion of human FcγRIIA, FcγRIIB, FcγRIIC, FcγRIIIA, and FcγRIIIB genes, and wherein the mouse comprises a functional mouse FcR γ–chain gene.

[0039] In one embodiment, the mouse comprises a deletion of the α-chains encoded by endogenous FcγRIIB, FcγRIV and FcγRIII genes and insertion of the α-chains encoded by human FcγRIIA, FcγRIIB, FcγRIIC, FcγRIIIA, and FcγRIIIB genes.

[0040] In one embodiment, the insertion of the human FcγRIIA, FcγRIIB, FcγRIIC, FcγRIIIA, and FcγRIIIB α-chain genes is at a random location within the mouse genome.

[0041] In one embodiment, the insertion of the human FcγRIIA, FcγRIIB, FcγRIIC, FcγRIIIA, and FcγRIIIB α-chain genes is at the endogenous mouse low affinity FcγR α-chain locus.

[0042] In one embodiment, the mouse expresses human FcγRIIIA on NK cells and macrophages. In a specific embodiment, all or substantially all NK cells from a splenocyte sample of the mouse express human FcγRIIIA. In a specific embodiment, all or substantially all macrophages from a splenocyte sample of the mouse express human FcγRIIIA.

[0043] In one embodiment, the mouse expresses a human FcγR selected from human FcγRIIA, human FcγRIIIA, and a combination thereof, on a cell type selected from neutrophils, macrophages, and a combination thereof. In a specific embodiment, the mouse expresses human FcγRIIA and human FcγRIIIA on all or substantially all neutrophils and macrophages of a splenocyte sample from the mouse.

[0044] In one embodiment, the mouse expresses human FcγRIIB and human FcγRIIIB on B cells and neutrophils of B cells from a B cell-gated splenocyte sample from the mouse. In a specific embodiment, the mouse expresses FcγRIIIB and FcγRIIB on all or substantially all B cells and neutrophils from a B cell-gated splenocyte sample from the mouse.

[0045] In one embodiment, the mouse further comprises a humanized CD20 gene. In one embodiment, the mouse that further comprises the humanized CD20 gene following treatment with an anti-CD20 binding protein that comprises an Fc exhibits depletion (*in vivo*) of B cells. In one embodiment, the depletion is in a compartment selected from bone marrow, blood, lymph node, spleen, and a combination thereof. In one embodiment, the Fc is a human Fc. In one embodiment, the Fc is a mouse Fc. In one embodiment, the anti-CD20 binding protein is an anti-CD20 antibody.

[0046] In one aspect, a cell is provided comprising a genetic modification as described herein. In one embodiment, the cell is selected from an embryonic stem (ES) cell, a pluripotent cell, an induced pluripotent cell, and a totipotent cell. In one embodiment, the cell is selected from a mouse cell and a rat cell. In a specific embodiment, the cell is an ES cell. In a more specific embodiment, the cell is a mouse ES cell.

[0047] In one aspect, a non-human embryo is provided, comprising a genetic modification as described herein. In one embodiment, the non-human embryo is selected from a mouse embryo and a rat embryo.

[0048] In one aspect, a method is provided for determining efficacy of a therapeutic. In one embodiment, the therapeutic is an antibody (*e.g.*, mono-, bi-, tri-, multispecific) comprising a

human Fc. In one embodiment, the therapeutic is a human antibody. In one embodiment, the efficacy is efficacy of therapeutic-mediated cell killing (*e.g.*, ADCC). In a specific embodiment, the human therapeutic is a fusion protein comprising an Fc of a human immunoglobulin heavy chain. In one embodiment, the therapeutic is administered to a mouse as described herein and a level of therapeutic-dependent ADCC is measured. In one embodiment, the mouse is used to assess the ADCC activity of a therapeutic by administering the therapeutic to the mouse and then detecting (*e.g.*, *in vitro* from a sample (*e.g.*, blood) taken from the animal) binding of the therapeutic to a human low affinity FcγR on an FcγR-expressing cell. In a specific embodiment, accessory cells of the mouse are isolated from the mouse and tested for the ability, in the presence and absence of the therapeutic, to mediate therapeutic-dependent ADCC.

[0049] In one aspect, a method is provided for determining whether a low affinity FcγR is associated with a human disease or disorder, comprising a step of determining a trait associated with the human disease or disorder in a mouse according to the invention. In one embodiment, the trait is a phenotype associated with the absence or loss of a function of one or more low affinity FcγRs. In a specific embodiment, the disease or disorder is an autoimmune disease or disorder. In a specific embodiment, the autoimmune disease or disorder is selected from Rheumatoid Arthritis (RA), Systemic Lupus Erythematosus (SLE), type I diabetes, Guillain-Barré syndrome, sclerosis, multiple sclerosis, Goodpasture's syndrome, Wegener's Granulomatosis and experimental autoimmune encephalomyelitis (EAE). In a specific embodiment, the mouse comprises a polymorphism in a low affinity FcγR, and the trait is selected from an enhanced ability to mediate ADCC in comparison to the majority of the human population that does not bear the polymorphism, and a reduced ability to mediate ADCC in comparison to the majority of the human population that does not bear the polymorphism.

[0050] In one aspect, a method for making an anti-human FcR α-chain antibody in a mouse is provided, comprising exposing a mouse according to the invention to a human FcR as described herein. In one embodiment, an antibody that recognizes the human FcR is isolated from the mouse. In another embodiment, a nucleic acid sequence that encodes all or part of a variable region of an antibody that recognizes the human FcR is identified and cloned.

[0051] In one aspect, a method for determining ability of anti-human FcR antibodies to target molecules to FcR-expressing cells for phagocytosis of the target molecule is provided, comprising exposing a mouse as described herein to an agent comprising an anti-human FcR antibody, and measuring phagocytosis of the target molecule.

[0052] In one aspect, a method is provided for making an antibody, in a mouse, to an antigen that is poorly immunogenic in a mouse that is wild type with respect to one or more FcγRs, comprising exposing a mouse as described herein that lacks a mouse low affinity FcR but expresses an FcγR γ-chain to the antigen that is poorly immunogenic in the mouse that is wild type with respect to one or more FcγRs, and identifying an antibody that recognizes the poorly antigenic antigen. In one embodiment, the method comprises isolating the antibody from the mouse. In another embodiment, a nucleic acid sequence that encodes all or part of a variable region of the antibody is identified and cloned.

[0053] In one aspect, a method for making a mouse capable of making antibodies comprising human variable regions is provided, comprising a step of breeding a first mouse as described herein with a second mouse that comprises (a) one or more human immunoglobulin variable region gene segments and one or more human constant region genes; or, (b) one or more human immunoglobulin variable region gene segments operably linked to a mouse constant region gene, wherein the human gene segments replace variable region gene segments at the mouse variable region gene segment locus.

[0054] In one embodiment, the second mouse (a) comprises a transgene that comprises one or more human immunoglobulin light chain variable region gene segments and a human light chain constant gene, and a transgene that comprises one or more human immunoglobulin heavy chain variable region gene segments and one or more human heavy chain constant genes. In one embodiment, the transgene that comprises one or more human immunoglobulin heavy chain variable region gene segments comprises two or more heavy chain constant genes and is capable of class switching. In a specific embodiment, the mouse comprises an inactivated endogenous light chain locus and/or an inactivated endogenous heavy chain locus. In a specific embodiment, the mouse comprises a deletion of an endogenous light chain locus and/or a deletion of an endogenous heavy chain locus.

[0055] In one embodiment, the second mouse (b) comprises human heavy and human light variable region gene segments, at the heavy an light mouse loci, respectively.

[0056] In one aspect, a method is provided for selecting an anti-tumor antibody, comprising a step of determining the ability of an antibody to mediate ADCC, wherein the ability of the antibody to mediate ADCC is tested by determining ADCC mediated by a cell of a mouse as described herein, and the antibody is selected if it mediates ADCC employing a cell of a genetically modified mouse as described herein. In a specific embodiment, binding of the

antibody to the cell of the genetically modified mouse is determined, and the anti-tumor antibody is selected for its ability to bind a human FcγR on the cell. In a specific embodiment, the human FcγR is a low affinity FcγR.

[0057] In one embodiment, the anti-tumor antibody is identified by its enhanced ability to mediate ADCC through a cell of the mouse as compared to ability of the anti-tumor antibody to mediate ADCC through a cell of a wild type mouse. In a specific embodiment, the anti-tumor antibody is identified by its ability to mediate ADCC through NK cells. In a specific embodiment, the NK cells express human FcγRIIIA.

[0058] In one embodiment, a method is provided for selecting an anti-tumor agent, comprising a step of administering an agent comprising a human Fc or a modified human Fc to a first non-human animal wherein the first non-human animal is genetically modified in accordance with the invention and comprises a human tumor; a step of administering the agent to a second non-human animal comprising the tumor; and determining the ability of the first non-human animal and the second non-human animal to retard growth of the human tumor following administration of the agent, wherein the agent is selected as an anti-tumor agent if it exhibits an enhanced ability to retard growth of the human tumor in the first non-human animal but not in the second non-human animal.

[0059] In one embodiment, the first non-human animal is modified to comprise a deletion of an endogenous FcR α-subunit, and is modified to comprise a human FcR α-subunit selected from the group consisting of an FcγRIIA α-subunit, an FcγRIIB α-subunit, an FcγRIIC α-subunit, an FcγRIIIA α-subunit, an FcγRIIIB α-subunit, and a combination thereof. In one embodiment, the second animal is a wild type animal. In one embodiment, the first non-human animal expresses an endogenous FcR γ-chain.

[0060] In one embodiment, the first non-human animal expresses a functional endogenous FcγRI.

[0061] In one aspect, a method is provided for making a mouse that lacks a low affinity mouse FcγR, expresses a functional FcR γ-chain, and comprises genes encoding α-chains of the human FcγRIIA, FcγRIIB, FcγRIIC, FcγRIIIA, and FcγRIIIB, comprising a step of replacing the low affinity mouse FcγR α-chains with human FcγR α-chains, at the mouse FcγR α-chain locus.

[0062] In one embodiment, a first step comprises deleting the α-chains of the endogenous FcγRIIB, FcγRIV and FcγRIII genes and inserting the α-chains of the human FcγRIIA and

FcγRIIIA genes; a second step comprises inserting the α-chains of the human FcγRIIB, FcγRIIC and FcγRIIIB genes into the mouse genome that results from the first step; wherein the mouse comprises a functional mouse FcR γ–chain gene. In a specific embodiment, the α-chains of the human FcγRIIB, FcγRIIC and FcγRIIIB genes of the second step are inserted 5' relative to the α-chains of the human FcγRIIA and FcγRIIIA genes of the first step.

[0063] In one aspect, a method for determining cell killing by a human therapeutic in a non-primate is provided, comprising a step of exposing a cell, non-human embryo, or non-human animal to a human therapeutic that comprises a human Fc, wherein the cell, embryo, or animal comprises a functional FcR γ-chain and comprises a replacement of one or more endogenous low affinity FcγR α-chain genes with one or more human FcγR α-chains, and determining the ability of the human therapeutic to mediate cell killing through a low affinity human FcγR of the cell, embryo, or animal.

[0064] In one embodiment, the non-primate is a mouse. In a specific embodiment, endogenous mouse FcγR α-chain genes FcγRIIB, FcγRIV and FcγRIII are replaced with human FcγR α-chain genes FcγRIIA, FcγRIIB, FcγRIIC, FcγRIIIA, and FcγRIIIB.

[0065] In one embodiment, the cell is selected from a B cell, a mast cell, a basophil, a macrophage, an eosinophil, a neutrophil, a dendritic cell, a Langerhans cell, and a combination thereof. In a specific embodiment, the cell is an NK cell and NK cell-mediated ADCC by a human or a humanized antibody is determined. In a specific embodiment, the low affinity human FcγR is a human FcγRIIIA.

[0066] In one aspect, a method for determining therapeutic-dependent thrombosis is provided, comprising exposing a first non-human animal that expresses a human FcγRIIA on a platelet to a therapeutic; exposing a second non-human animal that does not express the human FcγRIIA on a platelet to said therapeutic; measuring in the first non-human animal and in the second non-human animal an amount of therapeutic-dependent thrombosis; and, determining a difference in therapeutic-dependent thrombosis.

[0067] In one embodiment, the non-human animal is selected from a mouse and a rat.

[0068] In one embodiment, the determined difference in therapeutic-dependent thrombosis is employed to identify a risk associated with administering the therapeutic to a human. In one embodiment, the determined difference results in a change of administration of the therapeutic to a human patient in need thereof.

DETAILED DESCRIPTION

[0069] The invention is not limited to particular methods, and experimental conditions described, as such methods and conditions may vary. The terminology used herein is for the purpose of describing particular embodiments only, and is not intended to be limiting, since the scope of the present invention will be limited only by the claims.

[0070] Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by those of ordinary skill in the art to which this invention belongs. Although any methods and materials similar or equivalent to those described herein can be used in the practice or testing of the present invention, particular methods and materials are now described.

[0071] The phrase "targeting construct" includes a polynucleotide molecule that comprises a targeting region. A targeting region comprises a sequence that is substantially homologous to a sequence in a target cell, tissue or animal and provides for integration of the targeting construct into a position within the genome of the cell, tissue or animal. In a specific embodiment, the targeting construct further comprises a nucleic acid sequence or gene of particular interest, a selectable marker, control and or regulatory sequences, and other nucleic acid sequences that allow for recombination mediated through the exogenous addition of proteins that aid in or facilitate recombination involving such sequences. In another specific embodiment, the targeting construct further comprises a gene of interest, wherein the gene of interest is a heterologous gene that encodes a protein that has a similar function as a protein encoded by the endogenous sequence.

[0072] The term "replacement" includes wherein a DNA sequence is placed into a genome of a cell in such a way as to replace a sequence within a genome, at the locus of the genomic sequence, with a heterologous sequence (*e.g.*, a human sequence in a mouse), unless otherwise indicated. The DNA sequence so placed may include one or more regulatory sequences that are part of source DNA used to obtain the sequence so placed (*e.g.*, promoters, enhancers, 5'- or 3'-untranslated regions, *etc.*). For example, in various embodiments, the replacement is a substitution of an endogenous sequence for a heterologous sequence that results in the production of a gene product from the DNA sequence so placed (comprising the heterologous sequence), but not expression of the endogenous sequence; the replacement is of an endogenous genomic sequence with a DNA sequence that encodes a protein that has a similar function as a protein encoded by the endogenous genomic sequence (*e.g.*, the endogenous genomic sequence encodes a low affinity mouse FcγR receptor, and the DNA

fragment encodes one or more human low affinity FcγR receptors, such as, *e.g.*, a human FcγRIIC and/or an FcγRIIIB).

[0073] The term "FcγR" includes a receptor for an Fc, *e.g.*, an Fc portion of an IgG immunoglobulin. The FcγR genes include an α-chain that is expressed on the surface of the cell and serves as a ligand-binding domain, and associates with either a homodimer of the FcR γ–chain or a heterodimer of the FcR γ–chain and the δ-chain. There are several different FcγR genes and they can be categorized into low affinity and high affinity types according to preferential binding to IgG in immune complexes. Low affinity FcγR genes in humans include FcγRIIA, FcγRIIB, FcγRIIC, FcγRIIIA and FcγRIIIB and within most of these genes naturally occurring genetic differences, or polymorphisms, have been described in human subjects with autoimmune diseases. Persons of skill upon reading this disclosure will recognize that one or more endogenous low affinity FcγR genes in a genome (or all) can be replaced by one or more heterologous low affinity FcγR genes (*e.g.*, variants or polymorphisms such as allelic forms, genes from another species, chimeric forms, *etc.*).

[0074] The phrase "allelic variants" includes variations of a normal sequence of a gene resulting in a series of different forms of the same gene. The different forms may comprise differences of up to, *e.g.*, 20 amino acids in the sequence of a protein from a gene. For example, alleles can be understood to be alternative DNA sequences at the same physical gene locus, which may or may not result in different traits (e.g., heritable phenotypic characteristics) such as susceptibility to certain diseases or conditions that do not result in other alleles for the same gene or result in varying degrees in the other alleles.

[0075] An "accessory cell" includes an immune cell that is involved in the effector functions of the immune response. Exemplary immune cells include a cell of lymphoid or myeloid origin, *e.g.*, lymphocytes, natural killer (NK) cells, monocytes, macrophages, neutrophils, eosinophils, basophils, platelets, Langerhans cells, dendritic cells, mast cells *etc.* Accessory cells carry out specific functions of the immune system through receptors, *e.g.*, FcRs, expressed on their surfaces. In a specific embodiment, an accessory cell is capable of triggering ADCC mediated through an FcR, *e.g.*, a low affinity FcγR, expressed on the cell surface. For example, macrophages expressing FcRs are involved in phagocytosis and destruction of antibody-coated bacteria. Accessory cells might also be capable of releasing an agent that mediates other immune processes. For example, mast cells can be activated by antibody bound to FcRs to release granules, *e.g.*, inflammatory molecules (*e.g.*, cytokines) at a site of infection. In various

other embodiments, the expression of FcRs on accessory cells can be regulated by other factors (*e.g.*, cytokines). For example, FcγRI and FcγRIII expression can be inducted by stimulation with interferon-γ (IFN-γ).

Mouse and Human FcRs

[0076] The receptors for the Fc (*i.e.*, constant) regions of immunoglobulins (FcRs) play an important role in the regulation of the immune response. FcRs are present on accessory cells of the host's immune system to effectively dispose of foreign antigens bound by an antibody. FcRs also play important roles in balancing both activating and inhibitory responses of the accessory cells of the immune system. FcRs are involved in phagocytosis by macrophages, degranulation of mast cells, uptake of antibody-antigen complexes and modulation of the immune response, as well as other immune system processes.

[0077] In mice and humans, distinct FcRs are differentially expressed on the surface of different accessory cells that are each specific for the immunoglobulin isotypes present in the expressed antibody repertoire. For example, immunoglobulin G (IgG) antibodies mediate effector functions through IgG receptors (FcγRs). FcγRs have been classified into three groups: high affinity activating FcγRI (CD64), low affinity inhibitory FcγRII (CD32) and low affinity activating FcγRIII (CD16). Although each group is present in both mice and humans, the number of isoforms and subsets of immune cells on which they are present are different. For example, FcγRIIA and FcγRIIIB are expressed on accessory cells in humans but are reportedly absent from mice. Further, affinities of the different IgG isotypes (*e.g.*, IgG1) for each FcγR is different in mice and humans.

[0078] Activation or inhibition of cell signaling through FcγRs and the effector functions associated with antibody binding to FcγRs are believed to be mediated by specific sequence motifs of intracellular domains of FcγRs, or of the subunits of co-receptors. Activating receptors are most commonly associated with the common γ-chain (FcR γ–chain) which contains an immunoreceptor tyrosine-based activation motif (ITAM). ITAMs contain a specific sequence of about 9-12 amino acids that include tyrosine residues that are phosphorlyated in response to antibody binding to an FcR. Phosphorylation leads to a signal transduction cascade. Mice that lack a gene encoding an FcR γ–chain (FcR γ-chain KO) have been reported (*e.g.*, see Takai *et al.* (1994) FcR γ Chain Depletion Results in Pleiotrophic Effector Cell Defects, Cell 76:519-529; van Vugt *et al.* (1996) FcR γ-Chain Is Essential for Both Surface Expression and Function of

Human FcγRI (CD64) *In Vivo*, Blood 87(9):3593-3599; and Park *et al.* (1998) Resistance of Fc Receptor-deficient Mice to Fatal Glomerulonephritis, J. Clin. Invest. 102(6):1229-1238). The FcR γ–chain is reportedly essential for proper surface expression and function (*e.g.*, signal transduction, phagocytosis, *etc.*) of most of the FcRs; FcR γ-chain KO mice lack FcγRI according to some reports. However, other reports reveal that FcR γ-chain KO mice indeed express FcγRI on the surface of certain accessory cells, and the FcγRI expressed reportedly appears functional in that it binds IgG in mice in the absence of expressed FcR γ–chain (Barnes *et al.* (2002) FcγRI-Deficient Mice Show Multiple Alterations to Inflammatory and Immune Responses, Immunity 16:379-389).

[0079] In contrast, FcγRIIB is an inhibitory receptor that contains an immunoreceptor tyrosine-based inhibitory motif (ITIM) in its cytoplasmic domain. Like ITAMs, ITIMs are sequence motifs that include phosphorylatable tyrosine residues. However, downstream events following phosphorylation of an ITM lead to inhibition, not activation, of immune cell functions. Mice deficient in FcγRIIB reportedly exhibit an increased antibody response in comparison to wild type mice (Takai *et al.* (1996) Augmented humoral and anaphylactic responses in FcgRII-deficient mice, Nature 379:346-349), an observation that supports the role of FcγRIIB as a downregulator of the B cell antibody response.

[0080] In humans, FcγRIIA, FcγRIIB, FcγRIIC, FcγRIIIA and FcγRIIIB are considered the classical low affinity FcγR genes and are located together on the same chromosome (Su *et al.* (2002) Genomic organization of classical human low-affinity Fcγ receptor genes, Genes and Immunity 3 (Supple 1):S51-S56). These genes exhibit several polymorphisms associated with distinct phenotypes, *e.g.,* an alteration of ligand binding and function of the receptor. Some polymorphisms are associated with autoimmune diseases, *e.g.,* systemic lupus erythematosus (SLE), rheumatoid arthritis (RA), and multiple sclerosis (MS). Transgenic mice for different human FcγRs (hFcγRs) have been developed and used as disease models, generating high affinity antibodies, testing therapeutic antibodies for ability to elicit specific cellular responses, screening compounds that ameliorate aberrant immune responses, *etc.* (*e.g.*, see Heijnen *et al.* (1996) A Human FcgRI/CD64 Transgenic Model for In Vivo Analysis of (Bispecific) Antibody Therapeutics, J. Hematother. 4:351-356; Heijnen and van de Winkel (1996) Antigen Targeting to Myeloid-specific Human FcgRI/CD64 Triggers Enhanced Antibody Responses in Transgenic, J. Clin. Invest. 97(2):331-338; US Pat Nos. 6,111,166, 6,676,927, 7,351,875, 7,402,728, and 7,416,726).

[0081] Despite the significant roles of the FcRs in providing the bridge between antibodies and accessory cells of the immune system, no model system currently exists in which all the low affinity hFcγRs are expressed. A mouse in which all the low-affinity hFcγRs are co-expressed–including mice that lack endogenous mouse FcγRs—in various embodiments could be used to accurately reflect effects of a human antibody therapeutic, including ADCC-mediated effects. Such a mouse would serve as a vital tool in the engineering, analysis and evaluation of therapeutic antibodies for treatment of human diseases such as, *e.g.,* RA, type I diabetes, SLE, and autoimmunity, by providing an animal model capable of achieving a more accurate assessment of immunological processes in humans, particularly in the context of testing human antibody therapeutics. The mouse will also be a valuable source of cells bearing the low affinity receptors, which cells can be used in *in vitro* assays for assessing therapeutic-dependent cell killing for therapeutics that bind the low affinity receptors, and thus for identifying useful human therapeutics.

Endogenous Low Affinity FcγR Gene Deficient Mice

[0082] Genetically modified non-human animals are provided that do not express endogenous low affinity mouse FcγR genes, but that express an endogenous mouse FcR γ-chain. In various embodiments, the FcR γ-chain is expressed in a distribution (*i.e.*, in cell types) and at a level in the mouse that is the same or substantially the same as in a wild type mouse. Endogenous low affinity FcγR genes can be expressed either on the surface of immune cells or in a soluble manner in the periphery of the animals. Genetic modifications for making a non-human animal that does not express endogenous low affinity mouse FcγR genes are conveniently described by using the mouse as an illustration. A genetically modified mouse according to the invention can be made in a variety of ways, particular embodiments of which are discussed herein.

[0083] A schematic illustration (not to scale) of low affinity mouse FcγR gene locus is provided in Figure 1 (top) to show FcγR gene arrangement at the endogenous locus. As illustrated, low affinity mouse FcγR genes FcγRIIB, FcγRIV and FcγRIII are present together in close proximity on one chromosome. Each of these genes comprise the α-chain or ligand binding domain responsible for the binding the Fc portion of an antibody molecule.

[0084] A genetically modified mouse lacking a nucleotide sequence encoding an α-chain of the endogenous low affinity FcγR genes can be made by any method known in the art. For

example, a targeting vector can be made that deletes the low affinity mouse FcγR α-chain genes with selectable marker gene. Figure 1 illustrates a mouse genome (bottom) targeted by a targeting construct having a 5' homology arm containing sequence upstream of the endogenous low affinity FcγR α-chain locus, followed by a drug selection cassette (e.g. a neomycin resistance gene flanked by *lox*P sequences), and a 3' homology arm containing sequence downstream of the endogenous low affinity FcγR α-chain locus. Upon homologous recombination at the locus, the endogenous low affinity FcγR α-chain locus is replaced by a drug selection cassette (bottom of Figure 1). The endogenous low affinity FcγR α-chain gene locus is thereby deleted resulting in a cell or non-human animal that does not express endogenous low-affinity mouse FcγR α-chain genes. The drug selection cassette may optionally be removed by the subsequent addition of a recombinase (*e.g.*, by Cre treatment).

[0085] Genetically modifying a mouse to render an endogenous low-affinity mouse FcγR α-chain gene or genes nonfunctional, in various embodiments, results in a mouse that exhibits defects in immune responses, making the mouse useful for evaluating cooperative, as well as individual, roles of the endogenous low-affinity mouse FcγR genes in normal and disordered immune function, IgG-mediated processes, and autoimmune disease. In various embodiments, modifying the α-chains of the endogenous low-affinity mouse FcγR genes, but not the FcR γ–chain, avoids a potential reduction of other endogenous FcR genes (*e.g.*, high affinity FcγRI) that require the FcR γ–chain for surface expression and function, thus maintaining various other immunological functions and processes mediated through γ-chain-dependent processes.

[0086] According to some reports, FcR γ–chain deficient mice lack surface expression of FcγRIII and FcγRI. However, FcγRI has reportedly been detected on the cell surface in FcR γ–chain deficient mice and is reportedly at least partially functional. In contrast, mice according to the present invention contain unmodified endogenous FcR γ–chain, which preserves natural cell surface expression patterns and cellular functions of other FcR genes that require FcR γ-chain.

[0087] In various embodiments, mice of the present invention present an advantage over other FcγR gene-deficient mice in that the genetic modifications that they bear result in the maintenance of other genes necessary for other immunological functions not entirely devoted to low affinity FcγR genes. For example, with a functional FcR γ–chain, other γ-chain-dependent proteins (*e.g.*, FcγRI) will be able to associate with the FcR γ–chain and participate in effector

cell functions in the immune response. In various genetically modified mice in accordance with the invention, it is believed that maintaining such functions (due to the presence of a functional FcRγ–chain) while deleting endogenous low affinity FcγR genes (one or more α-subunits) enables a more precise elucidation of the roles of FcRs in autoimmunity.

Low Affinity FcγR Humanized Mice

[0088] Genetically modified non-human animals are provided that express low-affinity human FcγR genes. Low affinity human FcγR genes can be expressed either on the surface of accessory cells of the animal's immune system or in a soluble manner in the periphery of the animals.

[0089] The genetic modification, in various embodiments, comprises a deletion of a functional α-chain of one or more low-affinity mouse FcγR genes, and in some embodiments a further modification comprising a replacement with two or more, with three or more, with four or more, or with five low-affinity human FcγR α-subunit genes, wherein the non-human animal expresses a functional mouse FcR γ–chain gene. Genetically modified non-human embryos, cells, and targeting constructs for making the non-human animals, non-human embryos, and cells are also provided.

[0090] Compositions and methods for making a mouse that expresses a human FcγR gene, including specific polymorphic forms or allelic variants (*e.g.*, single amino acid differences), are provided, including compositions and method for making a mouse that expresses such genes from a human promoter and a human regulatory sequence. The methods include selectively rendering an endogenous low affinity mouse FcγR gene nonfunctional (*e.g.*, by a deletion of its α-chain), and employing an α-chain of a low affinity human FcγR gene at the endogenous low affinity mouse FcγR gene locus to express a low affinity human FcγR α-subunit gene in a mouse. The deletion of the low affinity mouse FcγR gene is made by deletion of one or more α-chain genes, but not an FcRγ-chain gene. The approach selectively renders one or more endogenous low affinity FcγR α-chain genes nonfunctional while retaining a functional endogenous FcRγ-chain.

[0091] The endogenous FcγR α-chain replacement approach employs a relatively minimal disruption in natural FcγR-mediated signal transduction in the animal, in various embodiments, because the genomic sequence of the FcγR α-chains are replaced in a single fragment and therefore retain normal functionality by including necessary regulatory sequences. Thus, in

such embodiments, the FcγR α-chain modification does not affect other endogenous FcRs dependent upon functional FcRγ-chain molecules. Further, in various embodiments, the modification does not affect the assembly of a functional receptor complex involving an FcγR α-chain and the endogenous FcR γ-chain, which is believed to be required for proper expression of some FcγR α-chains on the cell surface and for downstream signaling resulting from an activated receptor. Because the FcR γ-chain is not deleted, in various embodiments animals containing a replacement of endogenous FcγR α-chain genes with human FcγR α-chain genes should be able to process normal effector functions from antibodies through binding of the Fc portion of IgG immunoglobulins to the human FcγR α-chains present on the surface of accessory cells.

[0092] A schematic illustration (not to scale) of a deleted endogenous low affinity mouse FcγR gene is provided in Figure 4 (top). As illustrated, low affinity human FcγR genes FcγRIIA and FcγRIIIA are inserted into the deleted endogenous low affinity mouse FcγR gene locus by a targeting construct (Human FcγRIIIA-IIA Targeting Vector) with a genomic fragment containing the human low affinity human FcγRIIA and FcγRIIIA genes. Each of these genes comprise the α-chain or ligand-binding domain of the human FcγR genes responsible for the binding the Fc portion of an antibody molecule.

[0093] A genetically modified mouse that expresses low affinity human FcγR genes at the endogenous low affinity mouse FcγR locus can be made by any method known in the art. For example, a targeting vector can be made that introduces low affinity human FcγR genes (*e.g.*, FcγRIIA and FcγRIIIA) with a selectable marker gene. Figure 4 illustrates a mouse genome comprising a deletion of the endogenous low affinity FcgR locus (top). As illustrated, the targeting construct contains a 5' homology arm containing sequence upstream of the endogenous low affinity mouse FcγR locus, followed by a drug selection cassette (*e.g.*, a hygromycin resistance gene flanked on both sides by *lox*P sequences), a genomic fragment containing a human FcγRIIA gene, human HSP76 gene and human FcγRIIIA gene, and a 3' homology arm containing sequence downstream of the endogenous low affinity mouse FcγR locus. Upon homologous recombination at the deleted locus, the drug selection cassette is replaced by the sequence contained in the targeting vector (bottom of Figure 4). The endogenous low affinity FcγR gene locus is thus replaced with low affinity human FcγR genes resulting in a cell or animal that expresses low-affinity human FcγR genes. The drug selection

cassette may optionally be removed by the subsequent addition of a recombinase (*e.g.*, by Cre treatment).

[0094] For expression of hFcγRIIA on platelets, the targeting construct Human hFcγRIIA -IIA Targeting Vector comprises an extended sequence that includes, *e.g.*, all or substantially all of the human promoter region operably linked to the hFcgRIIA gene in a human genome. For preventing expression of hFcγRIIA on platelets, the targeting construct lacks all or substantially all of the human promoter region operably linked to the hFcγRIIA gene in a human.

[0095] Further modifications to the chimeric locus (bottom of Figure 4) can be achieved using similar techniques as described for replacement with two human FcγR genes. The modification to replace the endogenous low affinity FcγR gene locus with two human FcγR genes can further provide a starting point for incorporation of other low affinity human FcγR genes. For example, a schematic illustration (not to scale) of an endogenous low affinity FcγR locus replaced with two human low affinity FcγR genes is provided in Figure 6 (top). As illustrated, low affinity human FcγR genes FcγRIIB, FcγRIIC and FcγRIIIB are inserted into the modified endogenous low affinity mouse FcγR gene locus by another targeting construct (Human FcγRIIB-IIIB-IIC Targeting Vector) with a genomic fragment containing the low affinity human FcγRIIB, FcγRIIC and FcγRIIIB genes. Each of these genes comprise the α-chain or ligand-binding domain of the human FcγR genes responsible for the binding the Fc portion of an antibody molecule.

[0096] A genetically modified mouse that expresses five low affinity human FcγR genes at the endogenous low affinity mouse FcγR locus can be made by any method known in the art. For example, a targeting vector can be made that introduces low affinity human FcγR genes (*e.g.*, FcγRIIB, FcγRIIC and FcγRIIIB) with a selectable marker gene. Figure 6 illustrates a mouse genome comprising a replacement of the endogenous low affinity FcγR locus with two low affinity human FcγR genes (top). As illustrated, the targeting construct contains a 5' homology arm containing sequence upstream of the endogenous low affinity mouse FcγR locus, followed by a drug selection cassette (*e.g.*, a neomycin resistance gene flanked on both sides by *lox*P sequences), a genomic fragment containing a human FcγRIIB gene, a human FcγRIIIB, a human HSP77 gene, a human FcγRIIC gene, followed by a 3' homology arm containing sequence upstream of the low affinity human FcγRIIIA gene present at the endogenous locus. Upon homologous recombination at the modified locus, a human FcγRIIB, FcγRIIIB and FcγRIIC

gene are inserted 5' to the human FcγRIIIA and FcγRIIA genes previously present at the endogenous low affinity FcγR gene locus by the sequence contained in the targeting vector (bottom of Figure 6). The modified endogenous low affinity FcγR gene locus is thus further modified to incorporate three additional low affinity human FcγR genes resulting in a cell or animal that expresses five low-affinity human FcγR genes. The drug selection cassette may optionally be removed by the subsequent addition of a recombinase (*e.g.*, by Cre treatment). Figure 6 (bottom) shows the structure of the resulting locus, which will express five low affinity human FcγR genes that can be detected on the surface of accessory cells of the animal's immune system and independently associate, as appropriate, with an endogenous FcRγ-chain.

Experimental Models of FcγR Deficient Mice and FcγR Humanized Mice

[0097] Genetically modified non-human animals that do not express endogenous low affinity mouse FcγR genes are useful, *e.g.,* to elucidate the various functions of the individual low affinity FcγR genes in the immune response, to measure the efficacy of a human therapeutic antibody via cell-mediated immunity (*e.g.*, ADCC), to determine an FcγR's role in immune diseases or disorder, to serve as models of immune diseases or disorders, to generate antibodies against one or more FcγR proteins, and to serve as breeding mates to generate other genetically modified mice of interest.

[0098] In one embodiment, a mouse according to the invention can be used to determine a cytotoxic effect lost (in comparison to a wild type mouse) by a mouse that does not express low affinity FcγR genes by administering an agent to such a mouse, where the agent is known to trigger an FcγR-dependent cytotoxic effect in wild type mice. In one embodiment, a mouse of the present invention is implanted with tumor cells and, after a subsequent period of time, injected with an antibody specific for an antigen expressed on the surface of the tumor cells. The isotype of the antibody is known prior to injection and the animals are analyzed for impairment of FcγR-dependent ADCC by comparison to ADCC observed in wild type animals.

[0099] In another aspect, mice deficient in endogenous low affinity receptors could be combined (*e.g.*, by breeding) with other immune deficient mice to develop *in vivo* models of autoimmune disease. For example, Severe Combined Immunodeficiency (SCID) mice are routinely used in the art as model organisms for studying the immune system. SCID mice have an impaired ability to make T or B lymphocytes, or activate some components of the complement system, and cannot efficiently fight infections, reject tumors, and reject transplants.

Low affinity FcγR α-subunit gene-deficient mice of the present invention may be bred to SCID mice to ascertain cell depletion in a host animal in response to administration of an antibody therapeutic (*e.g.*, an anti-tumor antibody), which would determine the roles of ADCC and complement-dependent cytotoxicity (CDC) in tumor cell depletion *in vivo*.

[00100] In another aspect, genetically modified non-human animals comprising a replacement of the endogenous low affinity FcγR genes with low-affinity human FcγR genes are provided. Such animals are useful for studying the pharmacokinetics of fully human antibodies and hFcγR-mediated ADCC. In addition, human FcγR genes have been shown to exhibit polymorphisms or allelic variants associated with disease (*e.g.*, SLE, RA, Wegener's granulomatosis, Guillain-Barré syndrome and Multiple Sclerosis). Thus, genetically modified non-human animals that comprise a replacement of the endogenous low affinity FcγR genes with specific allelic or polymorphic forms of human FcγR genes can be used to study human autoimmune diseases, and traits associated with the polymorphisms, in the animal. In a specific embodiment, the allelic forms of human FcγR genes are associated with enhanced efficacy for human IgG.

[00101] In another specific embodiment, the affect of a human low affinity FcγR polymorphism on the efficacy of a human antibody therapeutic is determined. In a specific embodiment, an anti-tumor antibody is administered to a first humanized mouse comprising a first polymorphism of a human FcγR and also to a second humanized mouse comprising a second polymorphism of a human FcγR, wherein the first and the second mice each comprise a human tumor cell; and the anti-tumor activity of the anti-tumor antibody is assessed in the first mouse and in the second mouse. In a specific embodiment, a treatment option is selected by a physician with respect to treating a human having the first or the second polymorphism and having a tumor corresponding to the human tumor cell, based on the assessment of efficacy of the anti-tumor antibody in the first mouse and in the second mouse.

[00102] Suitable polymorphisms of human FcγR genes include all those known in the art. For the human FcγRIIA gene, polymorphisms include, *e.g.*, the high responder and low responder phenotype reported by the ability of T cells to proliferate in response to IgG. The high responder polymorphism is characterized by an arginine residue at position 131 (131Arg) while the low responder is characterized by a histidine residue at position 131 (131His). In a specific embodiment, the human FcγRIIA sequence comprises the 131His polymorphism. A representative protein sequence of the human FcγRIIA α-chain is shown in SEQ ID NO:32.

[00103] Single-nucleotide substitutions of the human FcγRIIB gene result in mis-sense substitutions in the ligand-binding domain (α-chain) and putatively affect the binding ability of an Fc portion of an IgG to bind to the α-chain of FcγRIIB on the cell surface. For example, substitution of a threonine residue for an isoleucine at position 232 (Ile232Thr) within the transmembrane domain of the FcγRIIB gene in mice has been shown to impair the signaling ability of the receptor. In a specific embodiment, the human FcγRIIB gene comprises the isoleucine variant (232Ile). A representative protein sequence of the human FcγRIIB α-chain is shown in SEQ ID NO:33.

[00104] Allelic variants of the human FcγRIIIA gene are proposed to be involved in susceptibility to SLE and RA. This allelic variant includes a phenylalanine substitution for valine at position 158 (Val158Phe). The valine allelic variant (158Val) is characterized to have a higher affinity for IgG1 and IgG3 than the phenylalanine allelic variant (158Phe). The 158Phe allelic variant has been proposed to lead to a reduced clearance of immune complexes. In a specific embodiment, the human FcγRIIIA gene comprises the 158Val allelic variant. A representative protein sequence of the human FcγRIIIA α-chain is shown in SEQ ID NO:35.

[00105] Allelic variants of the human FcγRIIIB gene include the neutrophil antigen 1 (NA1) and neutrophil antigen 2 (NA2) alleles. These allelic variants have been proposed to be involved in blood-transfusion reactions, alloimmune neutropaenia, SLE and Wegener's granulomatosis. The NA2 allelic variant is characterized by a diminished ability to mediate phagocytosis. In a specific embodiment, the human FcγRIIIB gene comprises the NA2 allelic variant. A representative protein sequence of the human FcγRIIIB α-chain is shown in SEQ ID NO:36.

[00106] In one aspect, the genetically modified non-human animals are useful for optimizing FcγR-mediated functions triggered by the Fc portion of therapeutic antibodies. The Fc regions of antibodies can be modified by any method known in the art. For example, amino acid residues within the Fc portion (*e.g.*, CH2 and CH3 domains) can be modified to selectively enhance the binding affinity to human FcγRIIIA. Thus, the resulting antibody should have enhanced FcγRIIIA-dependent ADCC. In a specific embodiment, an animal expressing human FcγRIIIA of the present invention is used to evaluate the enhanced ADCC ability of a modified human antibody by administering a modified human antibody to the animal, detecting (*e.g.*, *in vitro*) antibody binding to FcγRIIIA-expressing cells and comparing the ADCC activity observed to the ADCC activity observed from that determined in a wild type animal.

EXAMPLES

Example 1: Generation of Low Affinity FcγR Gene Deficient Mice

[00107] A targeting construct for introducing a deletion of the endogenous low affinity mouse FcγR locus (described below) was constructed (Figure 1).

[00108] The targeting construct was made using VELOCIGENE® technology (see, *e.g.*, US Pat. No. 6,586,251 and Valenzuela *et al.* (2003) High-throughput engineering of the mouse genome coupled with high-resolution expression analysis, Nature Biotech. 21(6):652-659) to modify the Bacterial Artificial Chromosome (BAC) RP23-395f6 (Invitrogen). RP23-395f6 BAC DNA was modified to delete the endogenous low affinity FcγRIIB, FcγRIV and FcγRIII genes comprising the α-chain of each of the FcγRs.

[00109] Briefly, upstream and downstream homology arms were made employing primers mFcR 5-up-1 (5'-ACCAGGATAT GACCTGTAGA G; SEQ ID NO:1) and mFcR 3-up-1a (GTCCATGGGT AAGTAGAAAC A; SEQ ID NO:2), and mFcR 5-DN (ATGCGAGCTC ATGCATCTATG TCGGGTGCGG AGAAAGAGGT AATGCATTCT TGCCCAATAC TTAC; SEQ ID NO:3) and mFcR 3-DN (ACTCATGGAG CCTCAACAGG A; SEQ ID NO:4), respectively. These homology arms were used to make a cassette that deleted the α-chains of the endogenous low affinity FcγRIIB, FcγRIV and FcγRIII genes. The targeting construct included a loxed neomycin resistance gene comprising homology arms comprising sequence homologous to a 5' and a 3' region with respect to the endogenous locus. Genes and/or sequences upstream of the endogenous FcγRIIB gene and downstream of the endogenous FcγRIII gene (see Figure 1) were unmodified by the targeting construct.

[00110] The targeted deletion was confirmed by polymerase chain reaction (PCR) using primers outside the deleted region and within the targeting construct. The upstream region of the deleted locus was confirmed by PCR using primers to mFcR-up-detect (ATCCTGAGTA TACTATGACA AGA; SEQ ID NO:5) and PGK-up-detect (ACTAGTGAGA CGTGCTACTT C; SEQ ID NO:6), whereas the downstream region of the deleted locus was confirmed using primers pA-DN-detect (CTCCCACTCA TGATCTATAG A; SEQ ID NO:7) and mFcR-DN-detect (TGGAGCCTCA ACAGGACTCC A; SEQ ID NO:8). The nucleotide sequence across the upstream deletion point included the following, which indicates endogenous mouse sequence downstream of the FcγRIIB gene (contained within the parentheses below) linked contiguously

to cassette sequence present at the deletion point: (GTCCATGGGT AAGTAGAAAC A)TTCGCTACC TTAGGACCGT TA (SEQ ID NO:9). The nucleotide sequence across the downstream deletion point included the following, which indicates cassette sequence contiguous with endogenous mouse sequence upstream of the FcγRIII gene (contained within the parentheses below): CGGGTGCGGA GAAAGAGGTA AT(GCATTCTT GCCCAATACT TA) (SEQ ID NO:10).

[00111] Mice deficient in FcγRIIB, FcγRIII and FcγRIV were generated through electroporation of a targeted BAC DNA (described above) into mouse ES cells. Positive ES cells clones are confirmed by Taqman™ screening and karyotyping. Positive ES cell clones were then used to implant female mice to give rise to a litter of pups deficient in low affinity FcγR genes.

Example 2: Characterization of Low Affinity FcγR Gene Deficient Mice

[00112] Spleens were harvested from FcγR deficient and wild type mice and perfused with 10 mL Collagenase-D in sterile disposable bags. Each bag containing a single spleen was then placed into a Stomacher® (Seward) and homogenized at a medium setting for 30 seconds. Homogenized spleens were transferred to 10 cm petri dishes and incubated for 25 minutes at 37°C. Cells were separated with a pipette using a 1:50 dilution of 0.5 M EDTA, followed by another incubation for five minutes at 37°C. Cells were then pelleted with a centrifuge (1000 rpm for 10 minutes) and red blood cells were lysed in 4 mL ACK buffer (Invitrogen) for three minutes. Splenocytes were diluted with RPMI-1640 (Sigma) and centrifuged again. Pelleted cells were resuspended in 10mL RPMI-1640 and filtered with a 0.2 µm cell strainer.

[00113] **Flow Cytometry**. Lymphocyte cell populations were identified by FACs on the BD LSR II System (BD Bioscience) with the following flourochrome conjugated cell surface markers: anti-CD19 (B cells), anti-CD3 (T cells), anti-NKp46 (NK cells) and anti-F4/80 (macrophages). Lymphocytes were gated for specific cell lineages and analyzed for expression of endogenous FcγRIII and FcγRIIB with a rat anti-mouse FcγRIII/II antibody (clone 2.4G2, BD Biosciences). Clone 2.4G2 recognizes a common polymorphic epitope on the extracellular domains of murine FcγRIII and FcγRII. The results show that there was no detectable murine low affinity FcγRIII or FcγRII on B-cells, NK cells and macrophages in mFcγR KO mice (Figure 2).

[00114] **ADCC Assay.** Splenocytes isolated from FcγR gene deficient and wild type mice were analyzed for their ability to perform ADCC in a cell-killing assay. Cell populations were

isolated and separated using MACS® Technology (Miltenyi Biotec). Briefly, T-cells were depleted from splenocytes using magnetically labeled anti-mouse CD3 beads. The T-cell depleted splenocytes were then enriched for NK cells using magnetically labeled anti-mouse CD49B beads. Separately, Raji cells (expressing human CD20) were coated with varying concentrations (ranging from 0.1 to 10 µg/mL) of mouse anti-human CD20 antibody (Clone B1; Beckman Coulter) for 30 minutes at 4°C. The antibody-coated Raji cells were incubated with the enriched NK cells at ratios (NK:Raji) of 100:1 and 50:1 for four hours at 37°C. Cell death was measured using the CytoTox-Glo™ Cytotoxicity Assay (Promega). Luminescence signal is derived from lysed cells and proportional to the number of dead cells. Luminescence from controls (no anti-CD20 antibody) was determined for background dead cell count for each ratio and subtracted from measurements for wild type and KO mice. Average cell death was calculated and percent decrease in cell killing (% ADCC) was determined by comparison to wild type. Results are shown in Table 1.

Table 1

	mFcγR KO	% ADCC		
		10 µg/mL B1 Antibody	1 µg/mL B1 Antibody	0.1 µg/mL B1 Antibody
NK cell:Raji cell	100:1	42	53	35
	50:1	15	0	0

Example 3: *In Vivo* Depletion of B cells in Low Affinity FcγR Gene Deficient Mice

[00115] The effect of human or murine Fc isotypes on B cell depletion through the ADCC pathway was determined for various B cell compartments in low affinity FcγR gene deficient mice engineered to express human CD20 using a human anti-human CD20 antibody. Mice expressing human CD20 were separately engineered using techniques known in the art. Mice that express human CD20 on B cells and deficient in low affinity FcγR genes (described in Example 1) were made by standard breeding techniques of the two engineered strains.

[00116] Separate groups of mice that expressed human CD20 and had a full complement of endogenous low affinity FcγR genes were each administered one of the following: (1) 10 mg/kg control antibody (N=4; human antibody not specific for human CD20 having a mouse IgG2a); (2) 2 mg/kg Ab 168 (N=3; human anti-hCD20 antibody with a mouse IgG2a; heavy and light chain variable region sequences found in SEQ ID NOs: 339 and 347, respectively, of US Patent

Publication No. 2009/0035322); (3) 10 mg/kg Ab 168; (4) 2 mg/kg Ab 735 (N=3; Ab 168 with human IgG1); (5) 10 mg/kg Ab 735. In a similar set of experiments, groups of mice that expressed human CD20 and had a deletion of the endogenous low affinity FcγR genes were administered the control and human anti-hCD20 antibodies (described above).

[00117] Mice in each group were administered the antibodies by intra-peritoneal injections. Seven days post-injection, animals were euthanized and the remaining B cell contents of bone marrow ($B220^+/IgM^+$), peripheral blood ($B220^+/CD19^+$), lymph node ($B220^+/CD19^+$) and spleen ($B220^+/CD19^+$) were identified by multi-color FACS performed on a LSR-II flow cytometer and analyzed using Flow-Jo software (as described above). The results of the B cell depletion experiments are shown in Figures 3A-3D.

[00118] As shown in Figures 3A-3D, Ab 735 depleted B cells with a lower efficiency than Ab 168 in mice containing a complete complement of low affinity FcγR genes. Further, for both antibodies (mouse and human Fc), B cell depletion was significantly reduced in mice lacking a complete complement of low affinity FcγR genes. This Example shows that the ability to deplete B cells through the ADCC pathway requires low affinity FcγRs and demonstrate that measuring ADCC efficiency for antibodies containing human constant regions in mice is more suitable by the use of genetically engineered mice containing a full complement of human low affinity FcγR genes.

Example 4: Generation of FcγRIIIA/FcγRIIA Humanized Mice

[00119] A targeting construct for introducing two low affinity human FcγR genes into a deleted endogenous low affinity mouse FcγR locus (described below) was constructed (Figure 4).

[00120] A targeting construct comprising human FcγRIIA and FcγRIIIA genes was made using similar methods (see Example 1) through modification of BAC RP23-395f6 and CTD-2514j12 (Invitrogen). BAC DNA of both BACs was modified to introduce a deletion of the α-chains of the low affinity human FcγRIIA and FcγRIIIA genes into the deleted endogenous low affinity FcγR locus.

[00121] In a similar fashion, upstream and downstream homology arms were made employing primers h14 (GCCAGCCACA AAGGAGATAA TC; SEQ ID NO:11) and h15 (GCAACATTTA GGACAACTCG GG; SEQ ID NO:12), and h4 (GATTTCCTAA CCACCTACCC C; SEQ ID NO:13) and h5 (TCTTTTCCAA TGGCAGTTG; SEQ ID NO:14), respectively. These

homology arms were used to make a cassette that introduced the α-chains of low affinity human FcγRIIA and FcγRIIIA genes into the endogenous mouse low affinity FcγR locus. The targeting construct included a 5' homology arm including sequence 5' to the deleted endogenous low affinity FcγR locus, a FRT'ed hygromycin resistance gene, followed by a human genomic fragment from BAC CTD-2514j12 comprising low affinity human FcγRIIA and FcγRIIIA α-chain genes, and a 3' homology arm comprising mouse sequence 3' to the deleted endogenous low affinity FcγR locus (middle of Figure 4). For a mouse that expresses FcγRIIA on mouse platelets, a targeting construct was made in a similar manner (using the same BACs) except that the construct comprises an extended promoter sequence operably linked to the human FcγRIIA gene in the human genome, e.g., up to about 18 kb or more, using a hygromycin cassette that is flanked on both sides by lox2372 sites, wherein the junction of the promoter region and the first lox 2372 site is ATCGGGGATA GAGATGTTTG (CC)GCGATCGC GGTACCGGGC (SEQ ID NO:37 human/lox2372 junction in parentheses) and wherein the junction of the second lox2372 site and mouse sequence is TTATACGAAG TTATACCGG(T G)CATTCTTGC CCAATACTTA (SEQ ID NO:38 lox2372/mouse junction in parentheses). Suitable primers were used to genotype the humanization comprising the promoter region.

[00122] Targeted insertion of the human FcγRIIA and FcγRIIIA α-chain genes was confirmed by PCR (as described above). The upstream region of the partially humanized locus was confirmed by PCR using primers h16 (CCCAGGTAAG TCGTGATGAA ACAG; SEQ ID NO:15) and pA-DN-detect (CTCCCACTCA TGATCTATAG A; SEQ ID NO:16), whereas the downstream region of the partially humanized locus was confirmed using primers mFcR DN-detect-9 (TGGAGCCTCA ACAGGACTCC A; SEQ ID NO:17) and h6 (CACACATCTC CTGGTGACTT G; SEQ ID NO:18). The nucleotide sequence across the downstream junction included the following, which indicates a novel insertion point of endogenous human sequence upstream of the hFcγRIIA gene (contained within the parentheses below) contiguous with endogenous mouse sequence 3' of the deleted low affinity FcγR locus: (CAACTGCCAT TGGAAAAGA)C TCGAGTGCCA TTTCATTACC TC (SEQ ID NO:19). The upstream junction includes two novel sequences. One point of the upstream junction includes the following, which indicates nucleotide sequence of the hygromycin cassette contiguous with human genomic sequence (contained within the parentheses below) that comprises the upstream region of the inserted hFcγRIIIA gene: TAAACCCGCG GTGGAGCTC(G CCAGCCACAA AGGAGATAAT CA) (SEQ ID NO:20). The second point of the upstream junction includes the following, which

indicates a nucleotide sequence of an endogenous mouse sequence (contained within the parentheses below) from the upstream region of the deleted low affinity FcγR locus contiguous with a nucleotide sequence within the hygromycin cassette: (CCATGGGTAA GTAGAAAC)TC TAGACCCCCG GGCTCGATAA CT (SEQ ID NO:21).

[00123] Mice containing two low affinity human FcγR genes (hFcγRIIA, lacking extended promoter region, and hFcγRIIIA) in place of the endogenous low affinity mouse FcγR locus were generated through electroporation of the targeted BAC DNA (described above) into mouse ES cells. Positive ES cells clones were confirmed by Taqman™ screening and karyotyping. Positive ES cell clones were then used to implant female mice using the VELOCIMOUSE® method (described below) to generate a litter of pups containing a replacement of the endogenous low affinity FcγR genes with the two human low affinity FcγR genes.

[00124] Targeted ES cells described above were used as donor ES cells and introduced into an 8-cell stage mouse embryo by the VELOCIMOUSE® method (see, *e.g.*, US Pat. No. 7,294,754 and Poueymirou *et al.* (2007) F0 generation mice that are essentially fully derived from the donor gene-targeted ES cells allowing immediate phenotypic analyses Nature Biotech. 25(1):91-99. VELOCIMICE® (F0 mice fully derived from the donor ES cell) bearing hFcγRIIA and hFcγRIIIA were identified by genotyping using a modification of allele assay (Valenzuela *et al., supra*) that detected the presence of the hFcγR genes.

[00125] Mice bearing the hFcγR genes can be bred to a Cre deleter mouse strain (see, *e.g.*, International Patent Application Publication No. WO 2009/114400) in order to remove any loxed neo cassette introduced by the targeting construct that is not removed, *e.g.*, at the ES cell stage or in the embryo. Optionally, the neomycin cassette is retained in the mice.

[00126] Pups are genotyped and a pup heterozygous for the hFcγR genes is selected for characterizing FcγRIIA and FcγRIIIA humanizations.

Example 5: Characterization of FcγRIIIA/FcγRIIA Humanized Mice

[00127] Spleens were harvested from humanized FcγRIIIA/FcγRIIA (heterozygotes, lacking the extended FcγRIIA promoter region) and wild type mice and prepared for FACs (as described above).

[00128] **Flow Cytometry.** Lymphocytes were gated for specific cell lineages and analyzed for expression of hFcγRII and hFcγRIII using a mouse anti-human FcγRII antibody (Clone FLI8.26; BD Biosciences) and a mouse anti-human FcγRIII antibody (Clone 3G8; BD

Biosciences), respectively. Relative expression (++, +) or no expression (-) observed for each lymphocyte subpopulation is shown in Table 2.

Table 2

Lymphocyte Lineage	hFcγRIII	hFcγRII
B cells	-	-
NK cells	++	-
Macrophages	+	+
Neutrophils	-	+

[00129] In a similar experiment, spleens were harvested from humanized FcγRIIIA/FcγRIIA (homozygotes, lacking the extended FcγRIIA promoter region) and wild type mice and prepared for FACs (as described above). Results are shown in Figures 5A and 5B. Percent of separate lymphocyte cell populations expressing human FcγRIIIA, FcγRIIA or both in FcγRIIIA/FcγRIIA homozygote mice is shown in Table 3.

Table 3

Lymphocyte Lineage	hFcγRIII	hFcγRII	hFcγRII/hFcγRIII
NK cells	97	-	-
Macrophages	26	14	39
Neutrophils	-	94	-

[00130] As shown in this Example, genetically modified mice (both heterozygote and homozygote genotypes) generated in accordance with Example 3 expressed human FcγRIIIA on NK cells and macrophages; and human FcγRIIA on neutrophils and macrophages, but not platelets. Human FcγRIIIA was highly expressed on NK cells. The expression pattern of human FcγR genes shown in this Example is consistent with the expression patterns of these genes in human accessory cells.

Example 6: Generation of Low Affinity FcγR Humanized Mice

[00131] A targeting construct for introducing three additional low affinity human FcγR genes into a partially humanized endogenous low affinity FcγR locus (described below) was constructed (Figure 6).

[00132] A targeting construct comprising human FcγRIIB, FcγRIIIB and FcγRIIC genes was made using similar methods (see Example 1) through modification of BAC RP-23 395f6 and RP-11 697e5 (Invitrogen). BAC DNA of both BACs was modified to introduce the α-chains of the low affinity human FcγRIIB, FcγRIIIB and FcγRIIC genes into the partially humanized endogenous low affinity FcγR locus containing two human low affinity FcγR genes.

[00133] In a similar fashion, upstream and downstream homology arms were made employing primers mFcR up-1 (ACCAGGATAT GACCTGTAGA G; SEQ ID NO:22) and mFcR2b NheI-2 (GTTTCTACTT ACCCATGGAC; SEQ ID NO:23), and h10 (AAATACACAC TGCCACAGAC AG; SEQ ID NO:24) and h11 (CCTCTTTTGT GAGTTTCCTG TG; SEQ ID NO:25), respectively. These homology arms were used to make a cassette that introduced DNA sequences encoding the α-chains of low affinity human FcγRIIB, FcγRIIIB and FcγRIIC. The targeting construct included a 5' homology arm including mouse sequence 5' to the deleted endogenous low affinity FcγR locus, a loxed neomycin resistance gene, followed by a human genomic fragment from BAC RP-11 697e5 comprising low affinity human FcγRIIB, FcγRIIIB and FcγRIIC α-chain genes, and a 3' homology arm comprising human sequence 5' to the low affinity human FcγRIIIA α-chain gene (middle of Figure 6).

[00134] Targeted insertion of three additional low affinity human FcγR genes was confirmed by PCR (as described above). The upstream region of the fully humanized locus was confirmed by PCR using primers mFcR up-detect-3 (GAGTATACTA TGACAAGAGC ATC; SEQ ID NO:26) and PGK up-detect (ACTAGTGAGA CGTGCTACTT C; SEQ ID NO:27), whereas the downstream region of the fully humanized locus was confirmed using primers neo detect (CTCCCACTCA TGATCTATAG A; SEQ ID NO:28) and h12 (CTTTTTATGG TCCCACAATC AG; SEQ ID NO:29). The nucleotide sequence across the downstream junction included the same human genomic sequence upstream of the hFcγRIIA α-chain gene (see Example 3; SEQ ID NO:19). The nucleotide sequence across the upstream junction included the following, which indicates two novel junctions of mouse and cassette sequences and cassette and human genomic sequences at the insertion point. The junction of genomic mouse sequence (contained within the parentheses below) and the upstream region of the neo cassette sequence is:

(GTCCATGGGT AAGTAGAAAC A)TTCGCTACC TTAGGACCGT TA (SEQ ID NO:30). The second novel junction includes the joining of the 3' end of neo cassette (contained within the parentheses below) and a human genomic sequence downstream of the hFcgRIIB α-chain gene: (GCTTATCGAT ACCGTCGAC)A AATACACACT GCCACAGACA GG; SEQ ID NO:31). These junctions are show in Figure 6 (middle) within the targeting construct. The resulting modified genome of the fully humanized low affinity FcγR locus is shown in Figure 6 (bottom).

[00135] Mice containing five low affinity human FcγR genes in place of the endogenous low affinity mouse FcγR locus were generated through electroporation of the targeted BAC DNA (described above) into mouse ES cells. Positive ES cells clones were confirmed by Taqman™ screening and karyotyping. Positive ES cell clones were then used to implant female mice (as described above) to give rise to a litter of pups containing a replacement of the endogenous low affinity FcγR genes for five human low affinity FcγR genes.

Example 7: Characterization of Low Affinity FcγR Humanized Mice

[00136] Spleens were harvested from fully humanized FcγR (heterozygotes) and wild type mice and prepared for FACs (as described above).

[00137] **Flow Cytometry.** Lymphocytes were gated for specific cell lineages and analyzed for expression of human FcγRIIA and FcγRIIIA using a mouse anti-human FcγRII antibody (Clone FLI8.26; BD Biosciences) and a mouse anti-human FcγRIII antibody (Clone 3G8; BD Biosciences), respectively. Relative expression (++, +) or no expression (-) observed for each lymphocyte subpopulation is shown in Table 4.

Table 4

Lymphocyte Lineage	hFcγRIII	hFcγRII
B cells	-	+
NK cells	+	+
Macrophages	+	+
Neutrophils	+	+

[00138] In a similar experiment, spleens were harvested from fully humanized FcγR (homozygotes) and wild type mice and prepared for FACs (as described above). Results are

shown in Figure 7. Percent of separate lymphocyte cell populations expressing human FcγRIIIA, human FcγRIIIB, human FcγRIIA, human FcγRIIB, human FcγRIIC or a combination thereof in fully humanized FcγR homozygote mice is shown in Table 5.

Table 5

Lymphocyte Lineage	hFcγRIII	hFcγRII	hFcγRII/hFcγRIII
B cells		100	
NK cells	30	-	-
Macrophages	<1	55	26
Neutrophils	-		100

[00139] As shown in this Example, genetically modified mice (both heterzyogote and homozygote genotypes) generated in accordance with Example 5 expressed human FcγRIIIA on NK cells and macrophages, human FcγRIIIB on neutrophils, human FcγRIIA on neutrophils and macrophages, human FcγRIIB on B cells, and human FcγRIIC on NK cells. The expression pattern of human FcγR genes shown in this Example is consistent with the expression patterns of these genes in human accessory cells.

Example 8: ADCC in Humanized FcγR Mice

[00140] Splenocytes isolated from FcγR gene deficient (*i.e.* knockout), FcγRIIIA/FcγRIIA (homozygotes), FcγRIIIA/FcγRIIIB/FcγRIIA/FcγRIIB/FcγRIIC (homozygotes) and wild type mice were analyzed for their ability to perform ADCC in a cell-killing assay (as described above in Example 2).

[00141] Briefly, cell populations were isolated and separated using MACS® Technology (Miltenyi Biotec). Briefly, T and B cell depleted splenocytes were cultured for two weeks in the presence of mouse IL-2 (500 U/mL). The resulting expanded NK cells were used as effector cells in the ADCC assays at a ratio of 50:1 (NK:Raji). Raji cells were coated with 10 ug/mL of Ab 168 or Ab 735 (as described above in Example 3). Results are shown in Table 6.

Table 6

NK Cell Genotype	% ADCC	
	10 µg/mL Ab 168	**10 µg/mL Ab 735**
Wild Type	89	72
Mouse FcγR KO	13	14
Human FcγRIIIA-IIA HO	78	85
Human FcγRIIIA-IIIB-IIA-IIB-IIC HO	81	59

[00142] The present invention is not to be limited in scope by the specific embodiments describe herein. Indeed, various modifications of the invention in addition to those described herein will become apparent to those skilled in the art from the foregoing description and the accompanying figures. Such modifications are intended to fall within the scope of the appended claims.

WE CLAIM:

1. A genetically modified mouse cell whose genome comprises a homozygous disruption of an endogenous FcγRIIB α-chain gene, a homozygous disruption of an endogenous FcγRIV α-chain gene, and a homozygous disruption of an endogenous FcγRIII α-chain gene.

2. The cell of claim 1, wherein the cell comprises a functional FcR γ-chain.

3. The cell of claim 1 or 2, wherein the cell is an embryonic stem (ES) cell.

4. A method of making a genetically modified mouse that does not express an endogenous gene encoding a FcγRIIB α-chain, an endogenous gene encoding a FcγRIV α-chain, and an endogenous gene encoding a FcγRIII α-chain, the method comprising transplanting the cell of claim 3 into a recipient mouse embryo, and obtaining a genetically modified mouse.

5. The method of claim 4, wherein the mouse comprises a reduced ability to make an immune response to an antigen as compared to a wild-type mouse with respect to the same antigen.

6. The method of claim 4 or 5, wherein the mouse comprises at least a 50% reduction in antibody-dependent cell-mediated cytotoxicity (ADCC) compared to a wild type mouse.

7. The method of any one of claims 4 to 6, wherein the mouse comprises a functional FcR γ-chain.

8. The cell of claim 1 or 2, wherein the cell is a natural killer (NK) cell.

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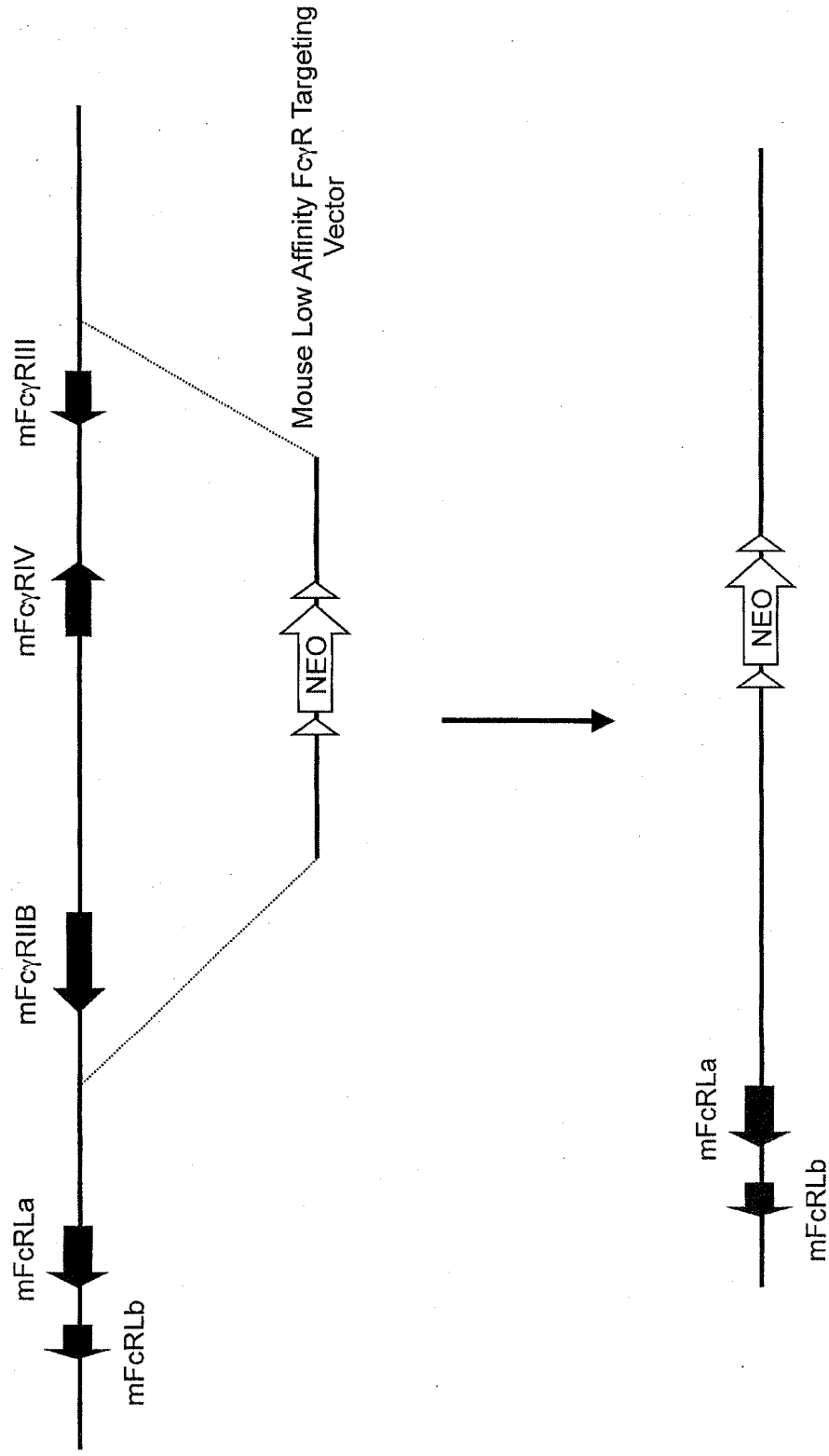
mFcγRIII
mFcγRIV
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mFcRLa
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Mouse Low Affinity FcγR Targeting Vector
NEO
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mFcRLa
mFcRLb

Figure 1

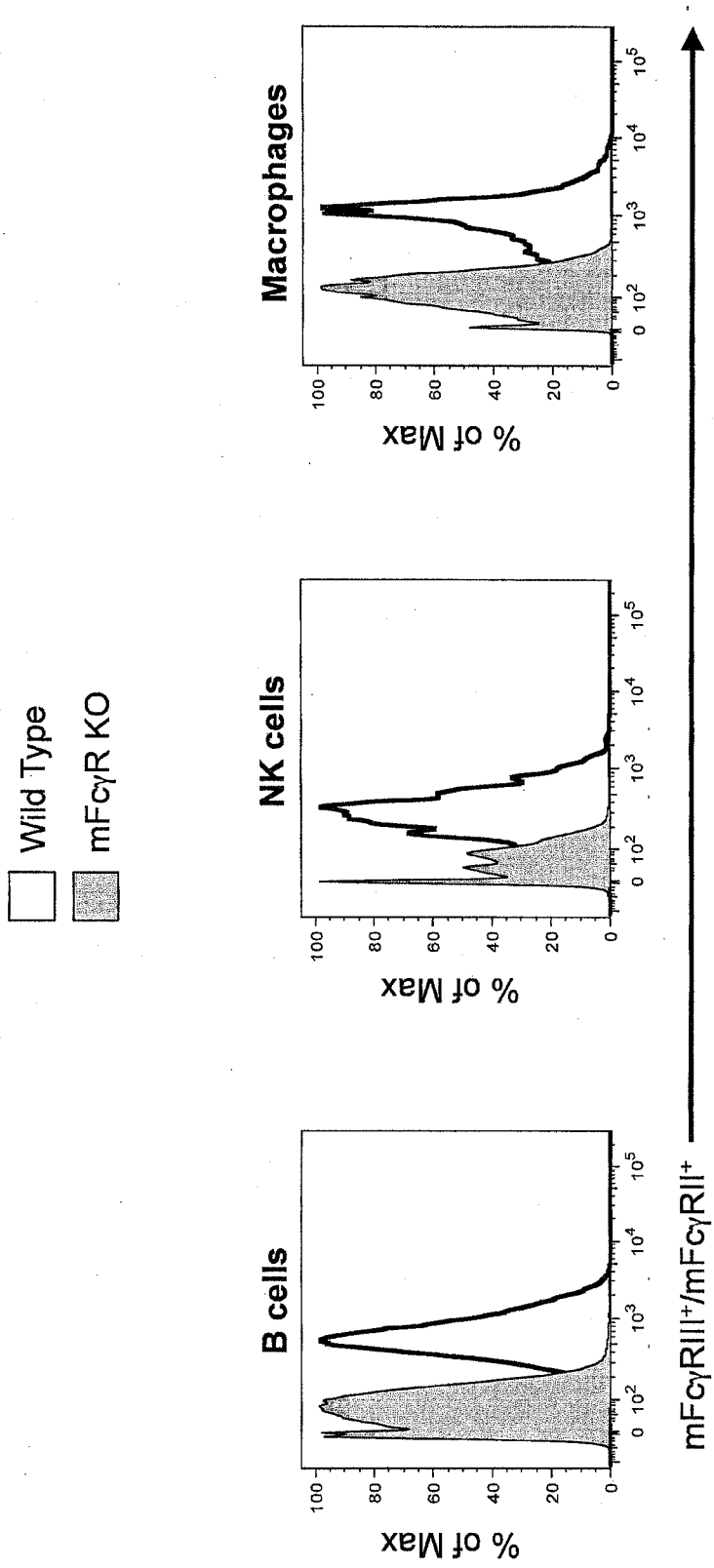
Wild Type
mFcγR KO
B cells
NK cells
Macrophages
% of Max
mFcγRIII+/mFcγRII+

Figure 2

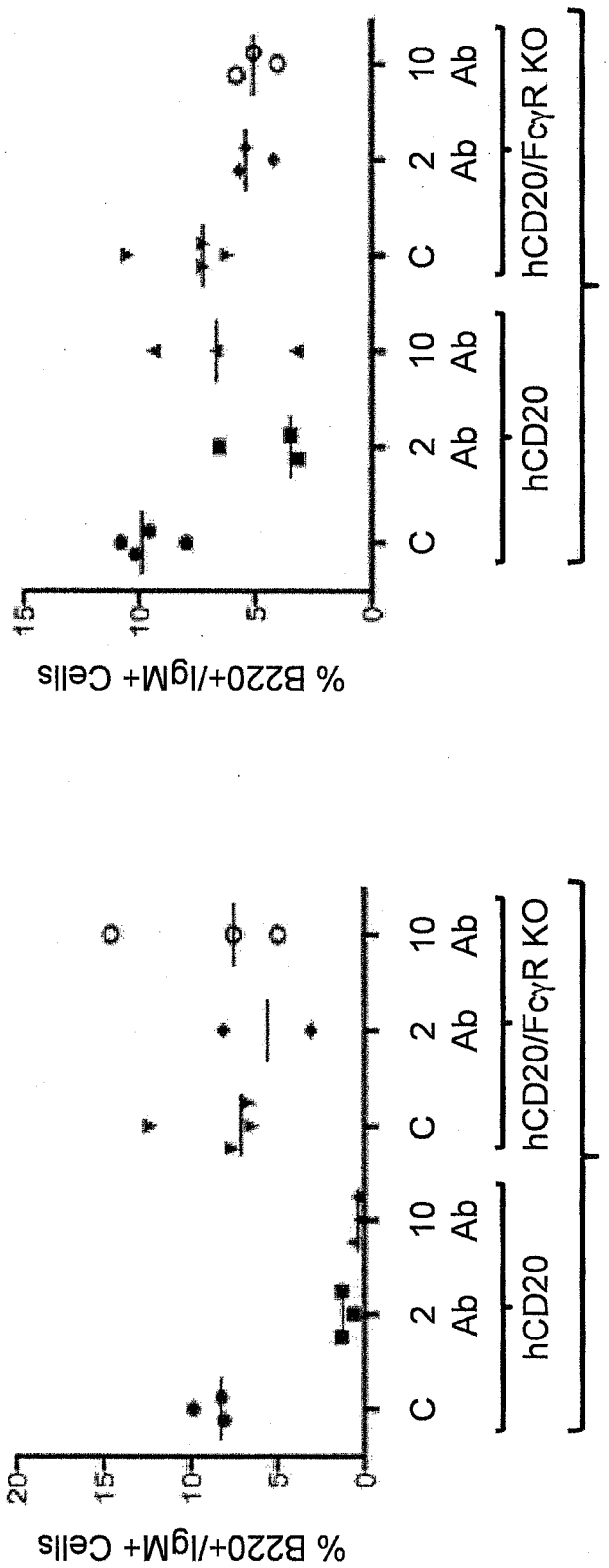
% B220+/IgM+ Cells
0
5
10
15
20
C
2 Ab
10 Ab
C
2 Ab
10 Ab
hCD20
hCD20/FcγR KO
Ab168
% B220+/IgM+ Cells
0
5
10
15
C
2 Ab
10 Ab
C
2 Ab
10 Ab
hCD20
hCD20/FcγR KO
Ab735

Figure 3A

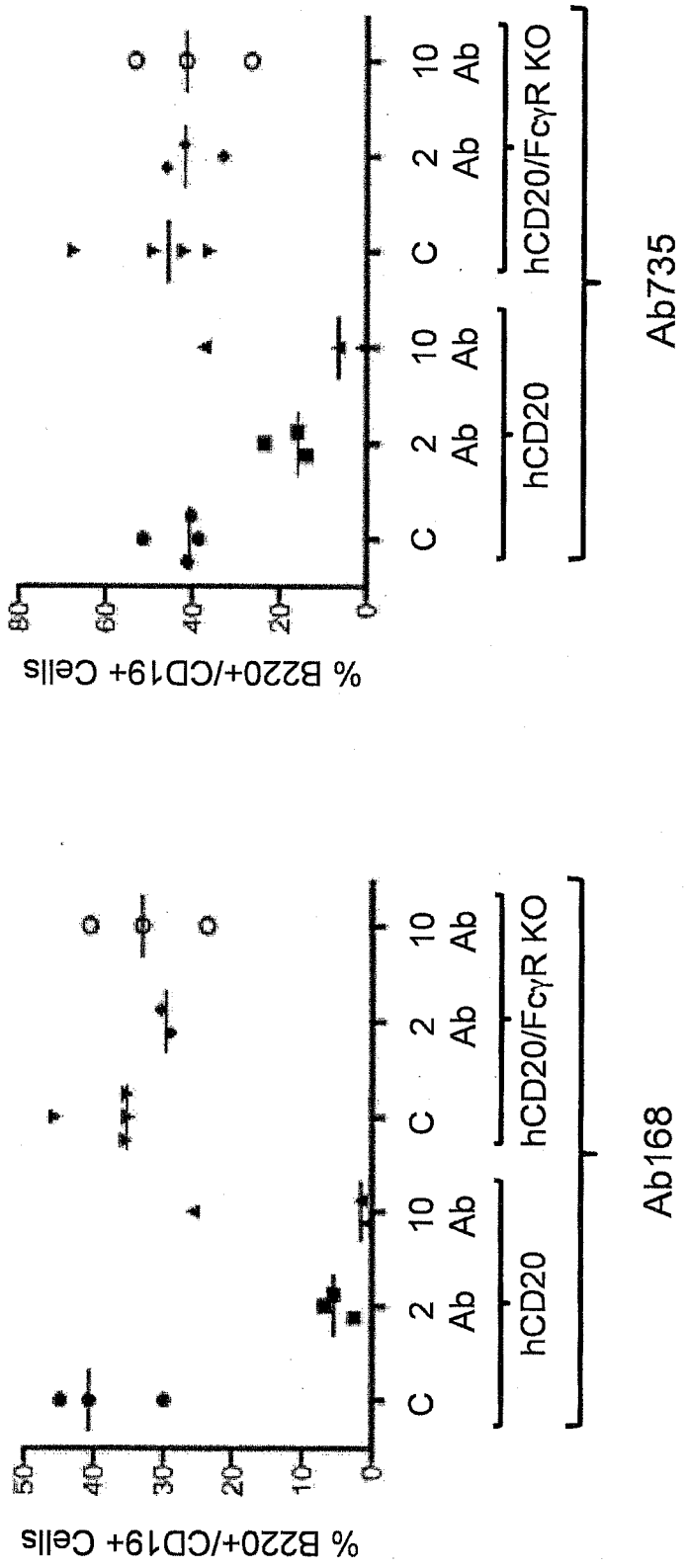

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Figure 3B

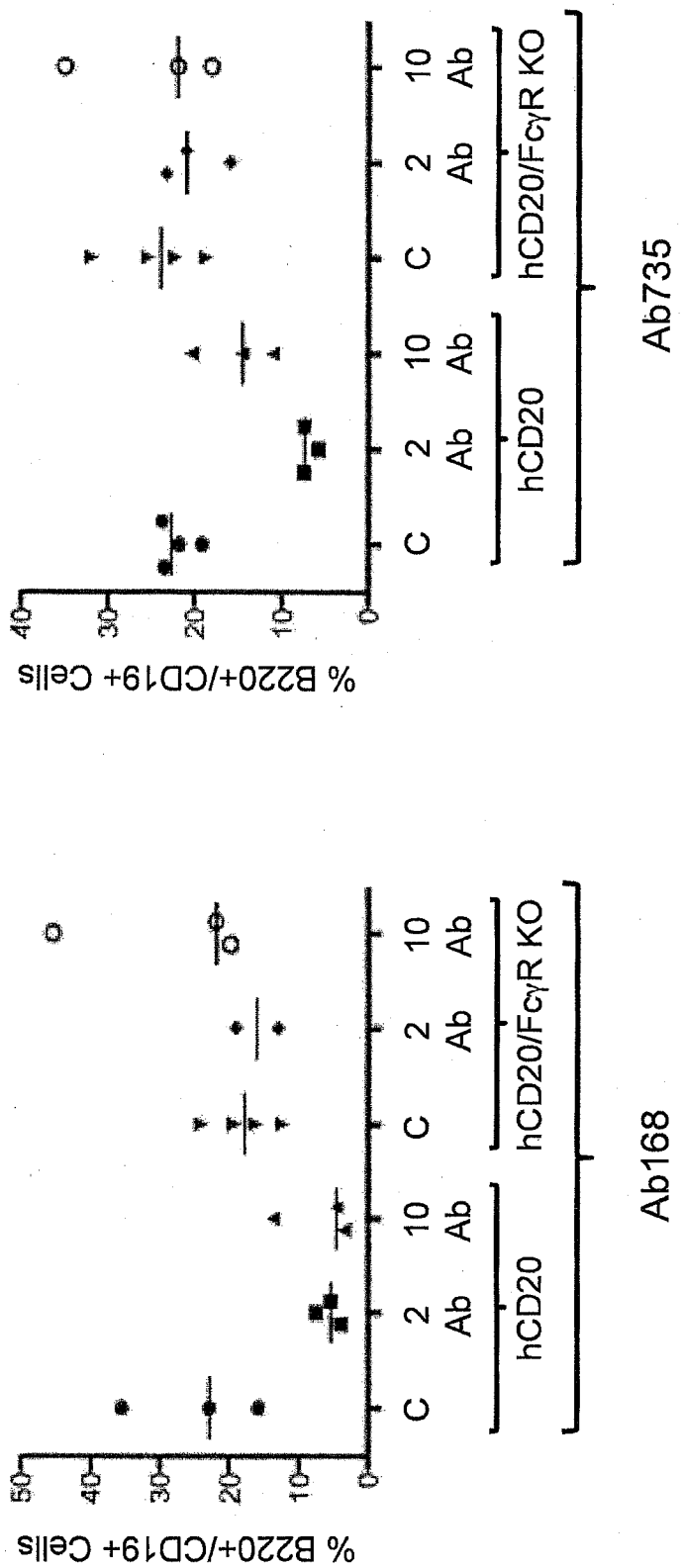
% B220+/CD19+ Cells
0
10
20
30
40
50
C
2
10
Ab
hCD20
hCD20/FcγR KO
Ab168
Ab735

Figure 3C

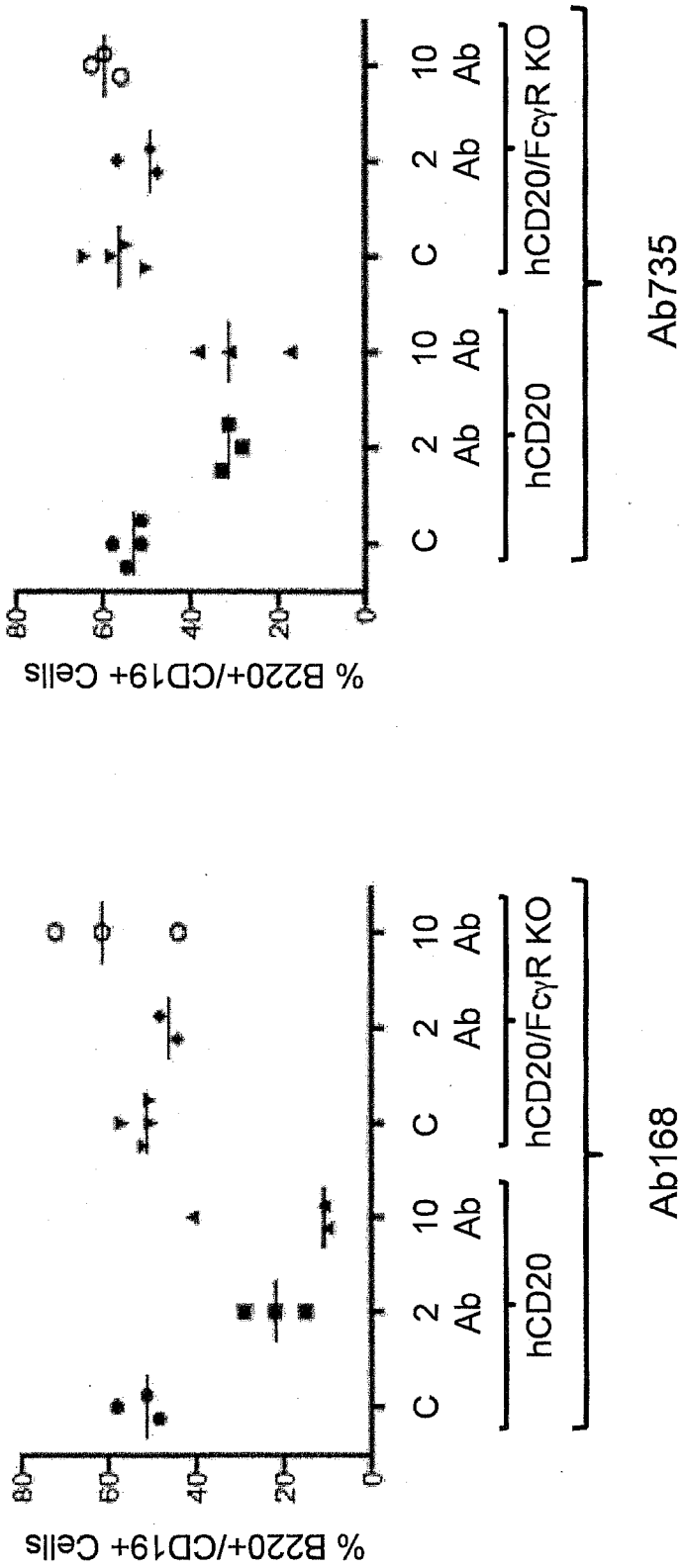

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Figure 3D

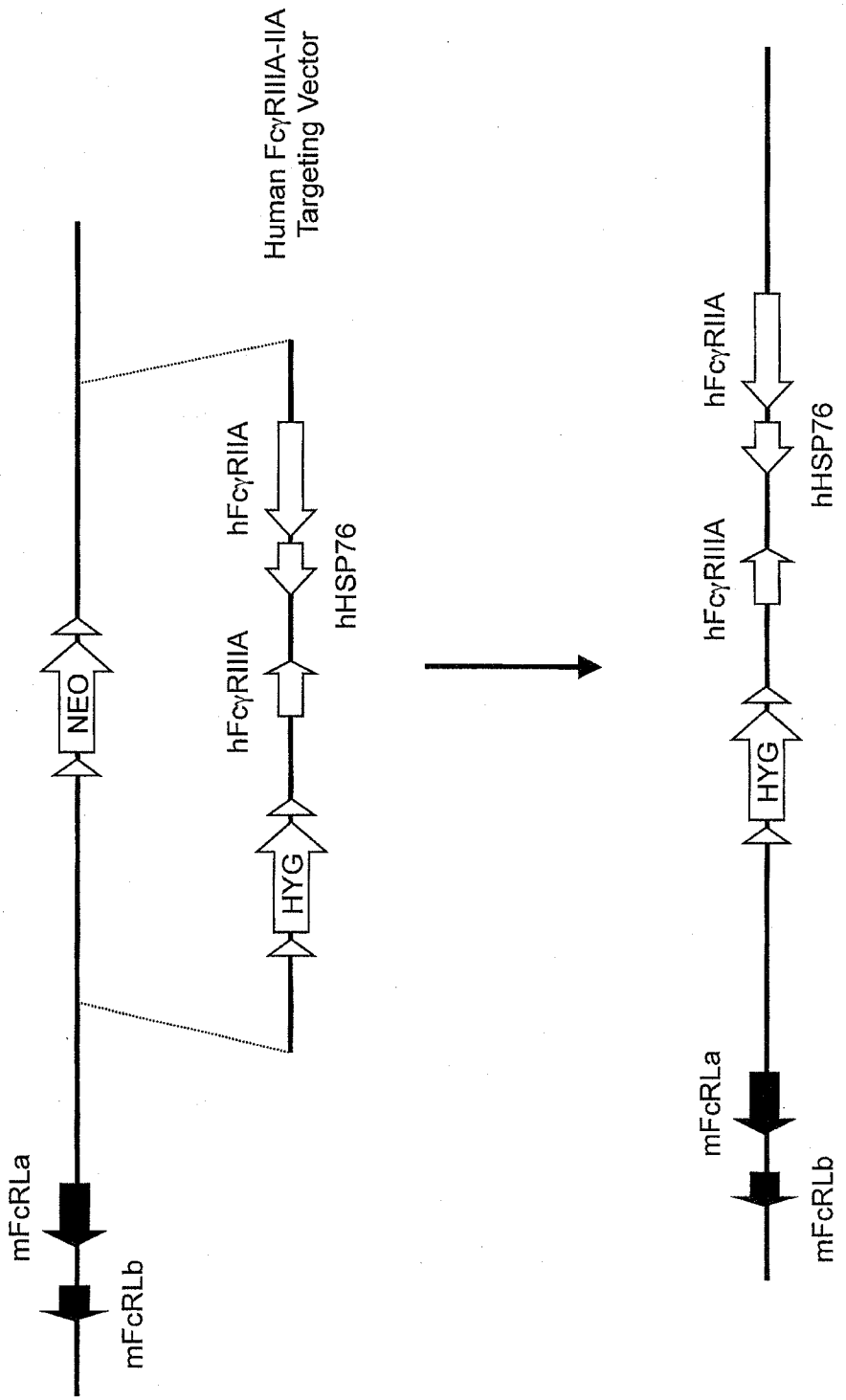

Human FcγRIIIA-IIA
Targeting Vector
NEO
hFcγRIIA
hHSP76
hFcγRIIIA
HYG
mFcRLa
mFcRLb
hFcγRIIA
hHSP76
hFcγRIIIA
HYG
mFcRLa
mFcRLb

Figure 4

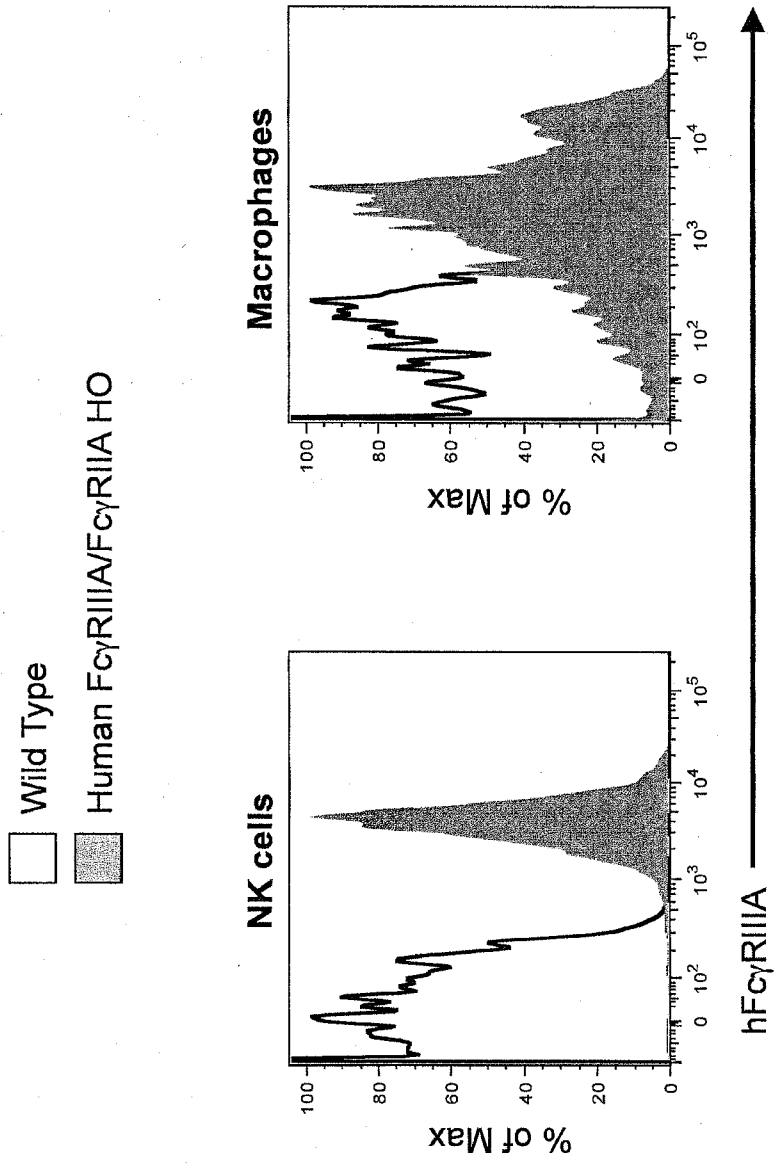

Wild Type
Human FcγRIIIA/FcγRIIA HO
NK cells
Macrophages
% of Max
hFcγRIIIA

Figure 5A

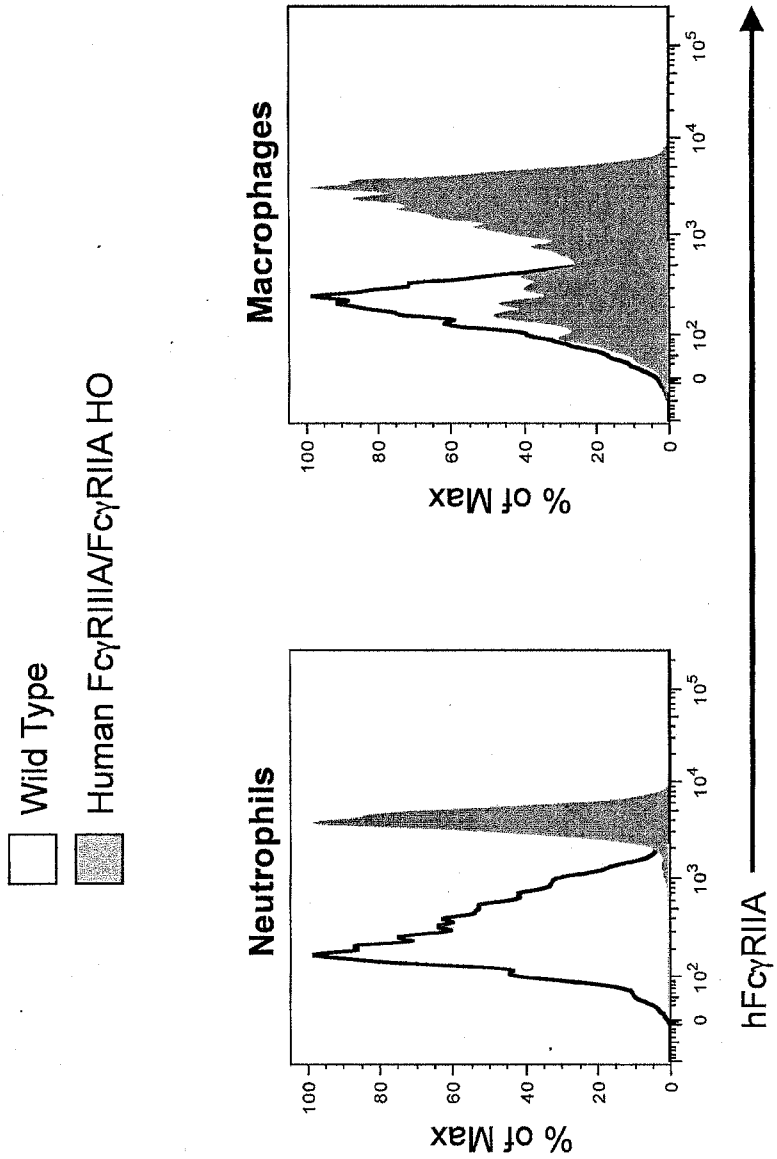

Wild Type
Human FcγRIIIA/FcγRIIA HO
Neutrophils
Macrophages
% of Max
hFcγRIIA

Figure 5B

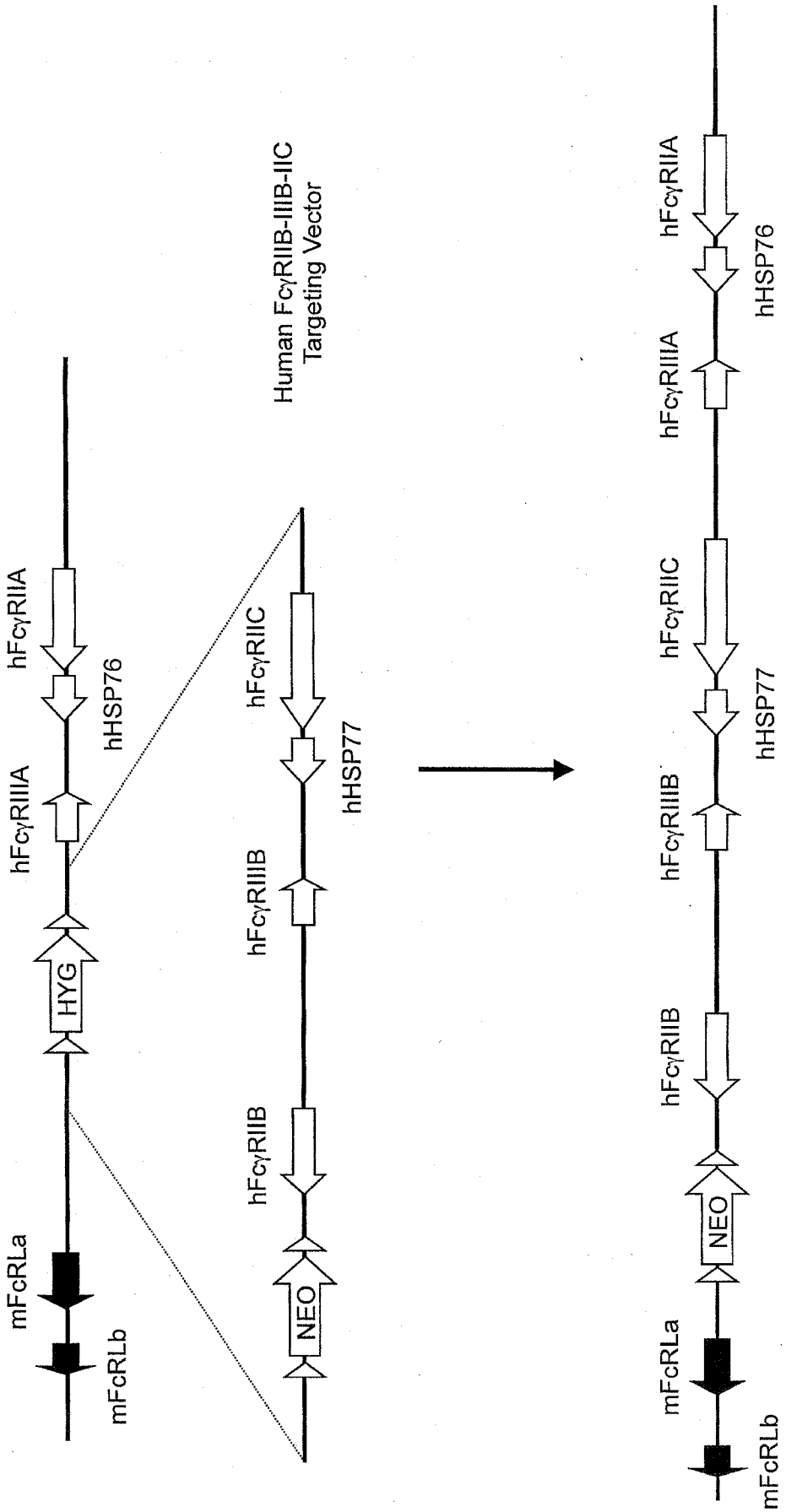

Human FcγRIIB-IIIB-IIC
Targeting Vector
hFcγRIIA
hHSP76
hFcγRIIIA
HYG
mFcRLa
mFcRLb
hFcγRIIC
hFcγRIIIB
hHSP77
hFcγRIIB
NEO
hFcγRIIA
hHSP76
hFcγRIIIA
hFcγRIIC
hHSP77
hFcγRIIIB
hFcγRIIB
NEO
mFcRLa
mFcRLb

Figure 6

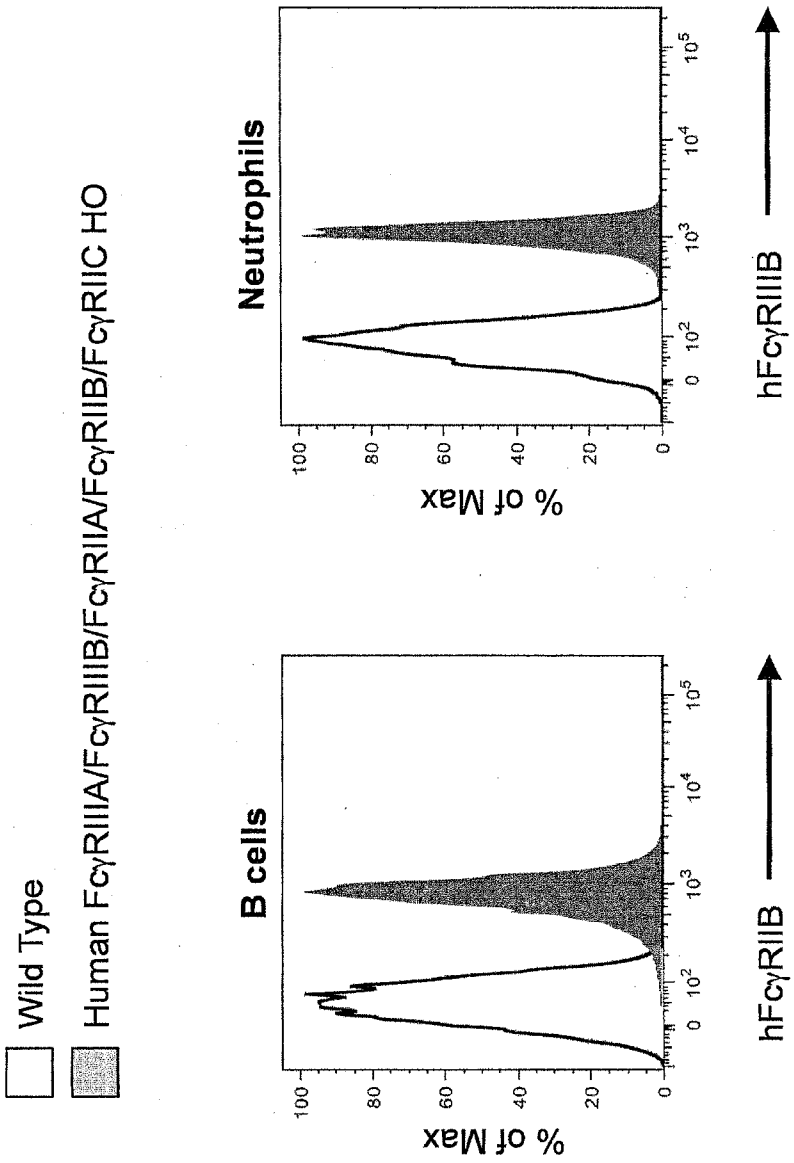
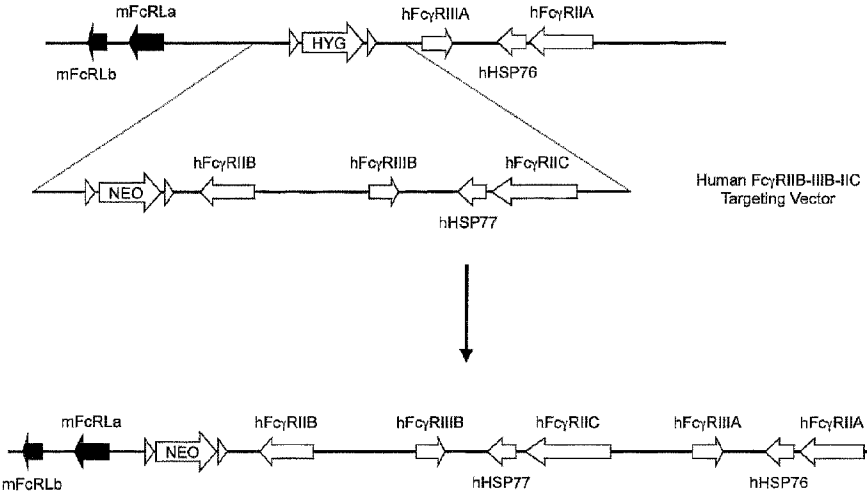

Wild Type
Human FcγRIIIA/FcγRIIIB/FcγRIIA/FcγRIIB/FcγRIIC HO
B cells
Neutrophils
% of Max
hFcγRIIB
hFcγRIIIB

Figure 7


mFcRLa
mFcRLb
HYG
hFcγRIIIA
hFcγRIIA
hHSP76
NEO
hFcγRIIB
hFcγRIIIB
hFcγRIIC
hHSP77
Human FcγRIIB-IIIB-IIC
Targeting Vector
mFcRLa
mFcRLb
NEO
hFcγRIIB
hFcγRIIIB
hFcγRIIC
hHSP77
hFcγRIIIA
hFcγRIIA
hHSP76