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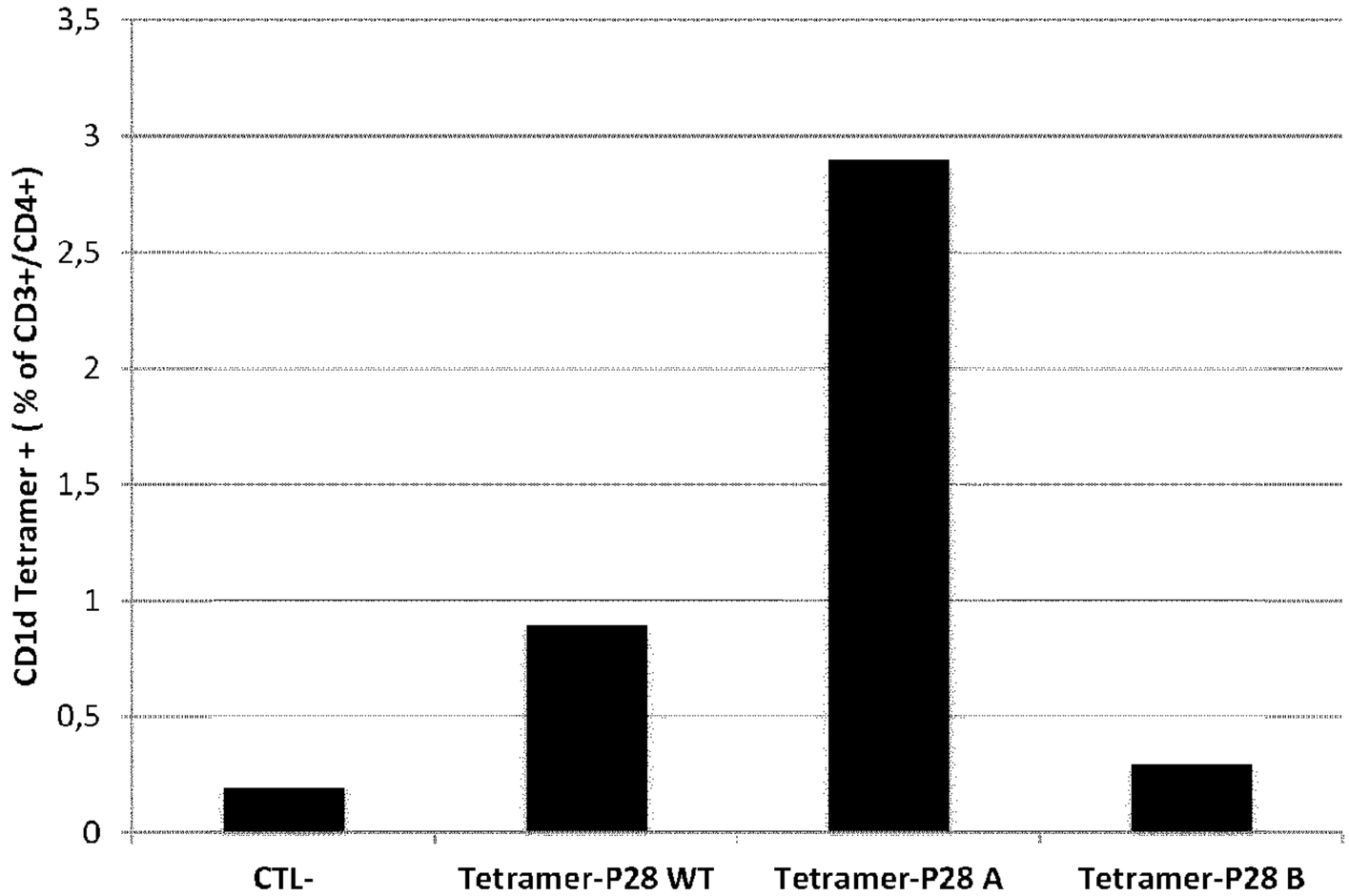
(54) Titre : FACTEUR VIII DE COAGULATION AYANT UNE IMMUNOGENICITE REDUITE
(54) Title: COAGULATION FACTOR VIII WITH REDUCED IMMUNOGENICITY

Figure 1



(57) Abrégé/Abstract:
The invention describes factor VIII molecules with reduced capacity to elicit activation of NKT cells for use in the treatment of congenital and/or acquired haemophilia A and in bleeding disorders. Said factor VIII molecule is obtainable by: a. identification of at least one NKT cell epitope wherein said epitope comprises hydrophobic aminoacid residues in position P1 and/or P7 b. modification of said epitope(s) by eliminating at least one hydrophobic aminoacid residue in position P1 and/or P7, substituting at least one hydrophobic aminoacid residue in position P1 and/or P7 with a non-hydrophobic residue, or adding a non-hydrophobic residue in position P1 and/or P7.

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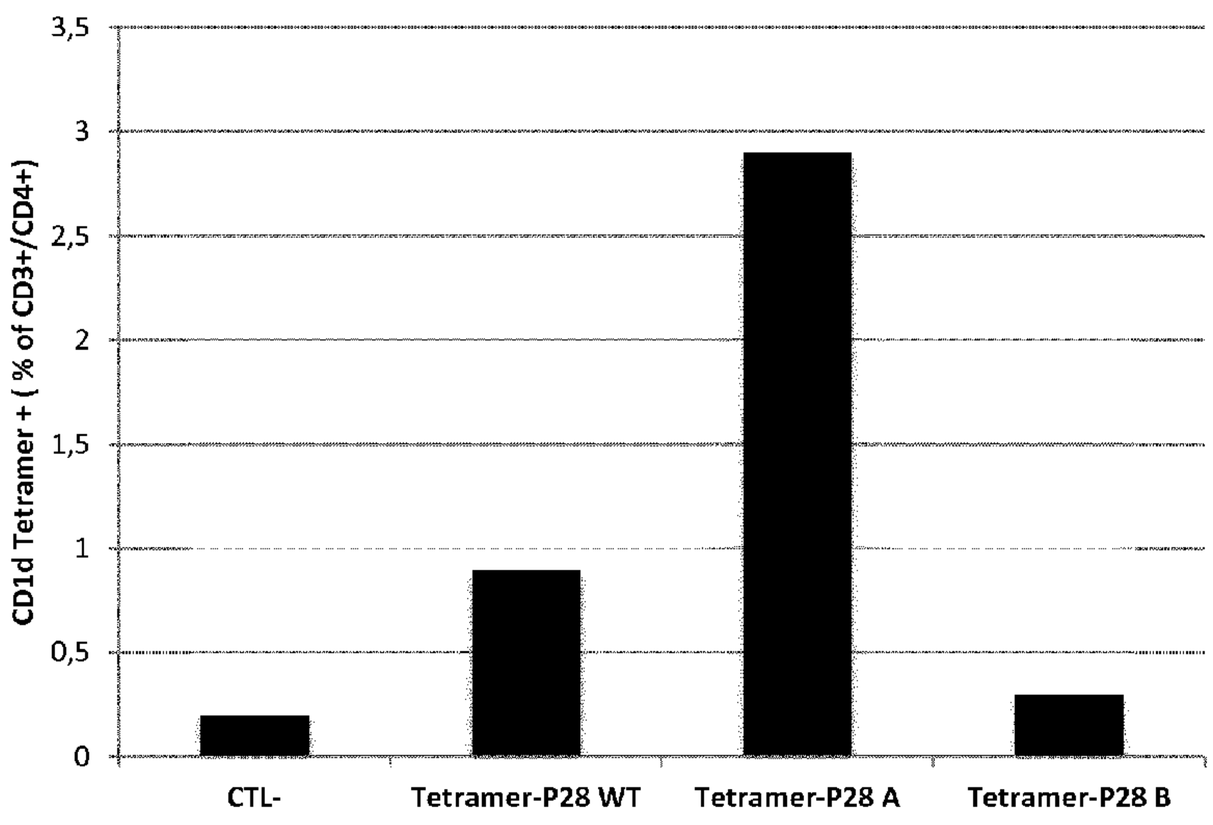
(54) **Title**: COAGULATION FACTOR VIII WITH REDUCED IMMUNOGENICITY

(57) **Abstract**: The invention describes factor VIII molecules with reduced capacity to elicit activation of NKT cells for use in the treatment of congenital and/or acquired haemophilia A and in bleeding disorders. Said factor VIII molecule is obtainable by: a. identification of at least one NKT cell epitope wherein said epitope comprises hydrophobic aminoacid residues in position P1 and/or P7 b. modification of said epitope(s) by eliminating at least one hydrophobic aminoacid residue in position P1 and/or P7, substituting at least one hydrophobic aminoacid residue in position P1 and/or P7 with a non-hydrophobic residue, or adding a non-hydrophobic residue in position P1 and/or P7.

Figure 1



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Coagulation factor VIII with reduced immunogenicity

Field of the invention

The present invention relates to molecules of coagulation factor VIII with reduced or lack of immunogenicity and their use in the therapy of coagulation disorders and in particular in the treatment of type A hemophilia.

Background of the invention

Factor VIII is a coagulation factor acting as a co-factor in the generation of thombin, an essential component of coagulation. In the absence or insufficiency of functional factor VIII, individuals suffer from bleeding disorders, collectively called hemophilia A. There are two types of hemophilia A, depending from its origin, either genetic (spontaneous hemophilia) or acquired (acquired or autoimmune hemophilia). Spontaneous hemophilia A is a disease affecting males due the location of the factor VIII gene on the X chromosome. Women are carriers but do not suffer from bleeding disorders because of the presence of 2 X chromosomes. Spontaneous hemophilia is further divided into 3 subsets of patients, defined according to the level of circulating factor VIII: severe hemophilia (less than 1% factor VIII), mild hemophilia (1 to 5% factor VIII) and moderate (factor VIII concentrations between 5 and 10%).

Patients suffering from hemophilia require a substitution therapy by factor VIII. This is a continuing therapy for severe hemophilia A patients due to the increased risk of spontaneous, sometimes life-threatening bleeding, or intermittent in mild or moderate hemophilia patients in whom factor VIII is required when there is a trauma or surgery and an acute demand of increased factor VIII concentrations.

By far the main complication patients suffering from hemophilia A have to face is the emergence of antibodies towards the therapeutic agent (factor VIII) used to restore a functional coagulation. There are currently 2 types of factor VIII used for replacement therapy, plasma-derived and recombinant. Plasma-derived factor VIII is produced from pools of human plasma

and contains additional proteins and in particluar the physiological chaperon of factor VIII, von Willebrand factor. Recombinant factor VIII is produced by genetic engineering and production by cells of animal or fo human origin. Recombinant factor VIII is pure and do not contain von Willebrand factor. Vivid controversy is ongoing to decide whether there is a significant difference in the risk of eliciting an anti-factor VIII immune response when using either plasma-derived or recombinant factor VIII molecule. Whatever the situation, on average 25% of patients receiving factor VIII as a therapeutic agent raise antibodies which inhibit the activity of the replacement agent. Such antibodies are called factor VIII inhibitors.

There is no cure for factor VIII inhibitors. On empirical grounds, it has been demonstrated that the administration of very high doses of factor VIII on a daily basis can result in some cases in a disappearance of inhibitors. This therapy, called induction of immune tolerance, is not reliable in its success. The lack of surrogate markers able to predict the outcome of immune tolerance de facto limits its use in an attempt to eliminate the formation of factor VIII inhibitors. Moreover, the prohibitive cost related to tolerance induction is such that only a few patients can be considered for tolerance induction.

Factor VIII inhibitors are high-affinity specific antibodies, which implies the participation of T lymphocytes in their formation. The consequence of this is that the immune response is fully memorized, leaving populations of memory B cells, which upon stimulation, transform into plasmocytes producing antibodies, and memory T cells which maintain the capacity to mount further antibody response upon each subsequent exposure to factor VIII. Patients presenting with factor VIII inhibitors can not be treated with factor VIII not only because inhibitors neutralize factor VIII function and, likely, increase the clearance rate of factor VIII, but also because each further exposure to factor VIII increases the concentrations of such inhibitors.

Patent application WO 2009/101206 describes a method by which it is possible to eliminate the production of inhibitors by acting at the level of adaptive immunity, namely at the level of the interaction between factor VIII-specific T and B cells. This application describes how the risk of producing new inhibitors upon factor exposure can be eliminated, but also how existing inhibitors can be eradicated. However, we have unexpectedly discovered that factor VIII is a

very potent activator of the innate immunity, which appears to be a pre-requisite for eliciting an adaptive response and inhibitors. Given that factor VIII has to be administered on a regular basis (e.g. 2 or 3 times a week for severe hemophilia A patients), and that therefore the risk of eliciting a new production of factor VIII inhibitors persists, there is an urgent need to define methods by which therapeutic factor VIII molecules could be produced, which have lost their capacity to activate the innate immunity.

The PCT application PCT/EP2011/070911 describes methods by which proteins with capacity to activate NKT cells can be transformed so as to loose such a capacity. Thus, NKT cells are part of the innate immune system, which is conventionally defined as lacking memorization. However, as described in PCT application PCT/EP2011/070911 NKT cells can recognize and be activated by the presentation of hydrophobic peptides by the CD1d molecule. As the peptide is derived from an antigen for which NKT cells are specific, this represent an antigen-specific innate immune system activation. The above-mentioned PCT application describes methods by which proteins showing the property to activate antigen-specific NKT cells can be modified by aminoacid substitution or deletion, thereby eliminating the capacity to bind to CD1d.

The present invention describes molecules of factor VIII obtained by the methodology described in PCT application PCT/EP2011/070911 which have lost their capacity to activate the innate immune system and, consequently, show a lack or significantly reduced capacity to active an adaptive immune response with production of inhibitors. The invention further describes the use of such factor VIII molecules for the treatment of patients in need for replacement therapy, and in particular severe hemophilia A patients. The present invention also discloses methods in which gene therapy using factor VIII molecules of the present invention can be used.

Summary of the invention

The present invention relates to the production of molecules of factor VIII with reduced immunogenicity.

The present invention also relates to the use of said factor VIII molecules for the treatment of patients in need for said treatment.

The PCT application PCT/EP2011/070911 describes methods to obtain peptides or polypeptides with reduced capacity to activate NKT cells. Thus, we made the unexpected finding that a significant proportion of peptides or polypeptides carried aminoacid sequences which allow them to bind and to be presented by CD1d determinants for activation of natural killer T (NKT) cells. Activation of such cells results in release of cytokines and, in some cases, in acquisition of, or increase in cytolytic properties.

The present invention relates in one aspect to the use of at least one isolated polypeptide used as an allofactor, which has been modified to eliminate at least one hydrophobic amino acid residue involved in the formation of an epitope recognized by NKT cells, for the manufacture of a medicament for preventing in a subject immune responses to said allofactor.

More specifically, the present invention relates to factor VIII and use of factor VIII as a medicament. Factor VIII is a co-factor of the coagulation system which participates to activation of thrombin by facilitating the formation of tenase, a serine esterase which assembles factor VIII, factor IX and factor X. Factor X carries the enzymatic activity converting thrombin. In the absence of factor VIII, the rate of tenase formation is drastically reduced, leaving the patients at risk of spontaneous bleedings, which are often life-threatening, and requires prompt therapeutic measures. When the concentration of factor VIII is moderately reduced (between 5 and 10%), the patients usually bleed only under trauma or surgery.

Patients suffering from severe hemophilia A (less than 1% factor VIII) have frequent spontaneous bleedings and require prophylactic treatment either on continuous administration or bolus injection 2 or 3 times a week. In additon, patients in whom an increased catabolism of factor VIII is observed, as in septic shock, acute fibrinolysis, polytrauma or cerebral hemorrhage, are also in need for factor VIII administration.

Definitions

The term "**peptide**" when used herein refers to a molecule comprising an amino acid sequence of between 2 and 200 amino acids, connected by peptide bonds, but which can in a particular embodiment comprise non-amino acid structures (like for example a linking organic compound). Peptides according to the invention can contain any of the conventional 20 amino acids or modified versions thereof, or can contain non-naturally occurring amino acids incorporated by chemical peptide synthesis or by chemical or enzymatic modification. The term "**polypeptide**" when used herein refers to generally longer peptides or proteins.

The term "**epitope**" when used herein refers to one or several portions (which may define a conformational epitope) of a protein which is/are specifically recognized and bound by an antibody or a portion thereof (Fab', Fab2', etc.) or a receptor presented at the cell surface of a B or T cell lymphocyte, and which is able, by said binding, to induce an immune response.

The term "**antigen**" when used herein refers to a structure of a macromolecule comprising one or more hapten(s) and/or comprising one or more T cell epitopes. Typically, said macromolecule is a protein or peptide (with or without polysaccharides) or made of proteic composition and comprises one or more epitopes; said macromolecule can herein alternatively be referred to as "**antigenic protein**" or "**antigenic peptide**".

The term "**T cell epitope**" or "**T-cell epitope**" in the context of the present invention refers to a dominant, sub-dominant or minor T cell epitope, i.e., a part of an antigenic protein that is specifically recognized and bound by a receptor at the cell surface of a T lymphocyte. Whether an epitope is dominant, sub-dominant or minor depends on the immune reaction elicited against the epitope. Dominance depends on the frequency at which such epitopes are recognized by T cells and able to activate them, among all the possible T cell epitopes of a protein. In particular, a T cell epitope is an epitope bound by MHC class I or MHC class II molecules.

The term "**NKT cell epitope**" refers to a part of an antigenic protein that is specifically recognized and bound by a receptor at the cell surface of a T lymphocyte. In particular, a NKT cell epitope is an epitope bound by CD1d molecules.

The term "**CD4+ effector cells**" refers to cells belonging to the CD4-positive subset of T-cells whose function is to provide help to other cells, such as, for example B-cells. These effector

cells are conventionally reported as Th cells (for T helper cells), with different subsets such as Th0, Th1, Th2, and Th17 cells.

The term **"NKT cells"** refers to cells of the innate immune system characterized by the fact that they recognize epitopes presented by the CD1d molecule. In the context of the present invention, NKT cells can belong to either the type 1 (invariant) subset (iNKT), or any other subset which would be activated by presentation of peptidic epitopes by CD1d. The term "NKT cells" also includes NKT cells belonging to either the CD4 or CD8 lineage. NKT cells often carry receptors such as NK1.1 and NKG2D.

The "**CD1d molecule**" refers to a non-MHC derived molecule made of 3 alpha chains and an anti-parallel set of beta chains arranged into a deep hydrophobic groove opened on both sides and capable of presenting lipids, glycolipids or hydrophobic peptides to NKT cells.

The term "**immune disorders**" or "**immune diseases**" refers to diseases wherein a reaction of the immune system is responsible for or sustains a malfunction or non-physiological situation in an organism. Immune disorders in the context of the present invention refer to pathology induced by infectious agents and tumor surveillance.

The term "**allofactor**" or **"alloantigen"** refers to a protein, peptide or factor (i.e. any molecule) displaying polymorphism when compared between two individuals of the same species, and, more in general, any protein, peptide or factor that induces an (alloreactive) immune response in the subject receiving the allofactor. By extension, allofactors also include genetically-modified proteins used for feeding.

Detailed description

The present invention provides factor VIII molecules to prevent in a subject an immune response towards said factor VIII molecules.

Factor VIII has a mature sequence made of 2332 amino acids with a domain structure A1-a1-A2-a2-B-a3-A3-C1-C2, in which A1, A2, B, A3, C1 and C2 represent domains and a1, a2 and a3 represent acidic regions linking said domains. Upon proteolytic processing, which occurs after secretion, factor VIII is present in plasma under a major form consisting of variable length

of A1-a1-A2-a2-B (the length is conditioned by the length of the B domain) linked noncovalently to light chains consisting of A3-C1-C2.

FVIII accelerates the activation of factor X by factor IX on a suitable phospholipid surface, thereby amplifying the clotting process . The active form of factor VIII is made of a heterotrimer consisting in A1-a1, A2-a2 and A3-C1-C2.

In particular, the invention provides ways to prevent the expansion and functional activity of NKT cells. Such cells are usually classified into distinct subsets, namely type 1 for NKT cells carrying an invariant TCR alpha chain (Valpha14 in the mouse, Valpha24 in humans), or type 2 NKT cells which present with a diverse alpha chain repertoire and is deemed to be specific for sulfatides. However, recent evidence has suggested that alternative subsets of NKT cells which do not fit in the type 1 or type 2 category. It is the purpose of the present invention to include these non conventional NKT cells, which can carry either the CD4 or the CD8 co-receptor. Upon presentation of an antigen bound to CD1d, NKT cells are rapidly activated and secrete a number of cytokines thought to be determinant to influence other cells from both the innate and adaptive immune systems. In some circumstances, said activated NKT cells acquire or increase cytotoxic properties.

In the context of the present invention, we made the unexpected observation that peptides can be presented by the CD1d molecule. A characteristic of the CD1d molecule is that it is made of two anti-parallel alpha chains forming a cleft sitting atop of a platform made of two anti-parallel beta chains. The cleft is narrow and deep and accept only hydrophobic residues, classically deemed to be only lipids. The cleft can accomodate a sequence of 7 aminoacids characterized as a hydrophobic residue in position (P)1 and 7, and an aliphatic residue in P4. P1 is an obligate hydrophobic residue, such as F, W, H or Y. However, P7 is permissive and can contain alternative residues provided they are not polar. Residues in P4 are preferably aliphatic but is optional. A general sequence for a CD1d binding motif is therefore [FWTHY]- X_2X_3-[ILMV]-X_5X_6-[FWTHY]. It should however be clear for those skilled in the art that the motif is symetrical and that P7 can be considered as P1, and P1 can be considered as P7. The general

sequence of a CD1d binding motif is provided here as a general indication without any limiting intention.

The present invention relates to the production of factor VIII molecules and method thereof, said molecules containing_CD1d binding motif(s), which confer them with the capacity to activate NKT cells and which are modified by elimination and/or substitution of hydrophobic residues in P1 and/or P7 with a non-hydrophobic residue, with the proviso that F in position 309 is not substituted by S and H in position 317 is not substituted by A, and/or adding a non-hydrophobic residue in position P1 and/or P7, with, optionally, substitution or deletion of aliphatic residues in P4, or any combination of these, which results in a loss or significant reduction of the capacity of peptides or polypeptides to bind to CD1d and thereby results in a loss or significant reduction of said peptides or poylpeptides to activate NKT cells.

The present invention therefore relates to a factor VIII molecule with a domain structure A1-a1-A2-a2-B-a3-A3-C1-C2, in which A1, A2, B, A3, C1 and C2 represent domains and a1, a2 and a3 acidic regions linking said domains said factor VIII molecule having a reduced capacity to activate NKT cells, said factor VIII molecules is obtainable by:

a. identification of at least one NKT cell epitope wherein said epitope comprises hydrophobic aminoacid residues in position P1 and/or P7

b. modification of said epitope(s) by eliminating at least one hydrophobic aminoacid residue in position P1 and/or P7, substituting at least one hydrophobic aminoacid residue in position P1 and/or P7 with a non-hydrophobic residue, or adding a non-hydrophobic residue in position P1 and/or P7.

The present invention also relates to methods to obtain a factor VIII molecule with reduced capacity to activate NKT cells comprising the steps of:

a. identification of at least one NKT cell epitope wherein said epitope comprises hydrophobic aminoacid residues in position P1 and/or P7

b. modification of said epitope(s) by eliminating at least one hydrophobic aminoacid residue in position P1 and/or P7, substituting at least one hydrophobic aminoacid residue in position P1

and/or P7 with a non-hydrophobic residue or adding a non-hydrophobic residue in position P1 and/or P7.

In a more particular embodiment, F, W, T, H or Y in positions P1 and/or P7 are replaced by a non-hydrophobic aminoacid residue, or, optionally, I, L, M or V in position P4 is replaced by a non-aliphatic residue, or any combination of these.

In yet another particular embodiment, hydrophobic residues located in position P1 and/or P7, or, optionally, aliphatic residues located in P4, or any combination of these, are replaced by at least one non-natural aminoacid different from non-natural F, W, T, H, Y, or by a non-aromatic organic compound.

In yet another particular embodiment at least one aminoacid is added within the CD1d binding motif, in any location within the P1 to P7 sequence, which disrupts the motif, prevents its capacity to bind to CD1d and thereby its capacity to activate NKT cells.

In a preferred embodiment, non-natural aminoacids are D-aminoacids.

The present invention also relates to the factor VIII molecules containing CD1d binding motif(s), which confer them with the capacity ot activate NKT cells, and which are modified by eliminating at least one hydrophobic aminoacid residue in position P1 and/or P7, substituting at least one hydrophobic aminoacid residue in position P1 and/or P7 with a non-hydrophobic residue, or adding a non-hydrophobic residue in position P1 and/or P7, and additionally, by deletion of aliphatic residues in P4, or any combination of these, which results in a loss or significant reduction of the capacity of peptides or polypeptides to bind to CD1d and thereby results in a loss or significant reduction of said peptides or poylpeptides to activate NKT cells.

Upon administration to a subject, such factor VIII molecules are not loaded on CD1d and thereby are prevented from activating NKT cells.

In a further aspect, the invention also covers the use of factor VIII molecules comprising at least one substitution or deletion of F, W, T, H or Y in positions P1 or P7 for preventing in a subject an immune response towards factor VIII.

In yet a further aspect, the invention covers the use of factor VIII molecules comprising at least one substitution or deletion of F, W, T, H or Y in positions P1 or P7 for preventing in a subject the activation of NKT cells towards factor VIII.

In yet a further aspect, the invention also covers the use of factor VIII molecules comprising at least one substitution or deletion of F, W, T, H or Y in positions P1 or P7 for the manufacture of a medicament for preventing in a subject an immune response towards factor VIII.

The number of CD1d binding motifs when present in a peptide or polypeptide, is very limited. Examples of such peptides or polypeptides are provided below for factor VIII. Typically a polypeptide presents one to five of these motifs.

An additional advantage of the present invention is that the CD1d molecule presents a very limited degree of polymorphism. It is therefore obvious for the one skilled in the art that the same aminoacid substitutions, addition or deletions according to the present invention provide peptides or polypeptides useful for all or a large majority of subjects. This is in sharp contrast with peptide or polypeptide motifs binding to MHC class II molecules, wherein a large number of peptides can be delineated which contain the appropriate sequence. This is due to the minimum constraints imposed to MHC class II binding peptides and to the large polymorphism of class II molecules.

Factor VIII molecules which are the object of the present invention are identified as follows:

(1) optionally, the aminoacid sequence of factor VIII is evaluated for the presence of at least one CD1d motif containing an hydrophobic residue in P1 and P7, and an aliphatic residue in P4. A general sequence such as [FWTHY]- X_2X_3-[ILMV]-X_5X_6-[FWTHY] can be used for using algorithms well known in the art such as
http://expasy.org/tools/scanprosite/

This general sequence should be considered as a tool to help identifying which sequence(s) in said peptide or polypeptide contain a motif which could enable said peptide or polypeptide to activate NKT cells.

(2) the capacity of the peptide or polypeptide to bind to CD1d is tested in vitro using a cell line expressing the CD1d molecule. Examples of such cell lines are known in the art and used to produce examples in the present application (for instance, JAWS2 cells and U937 cells). In a preferred embodiment, the cell line is not presenting MHC class II molecules and is transduced for hyperexpression of CD1d using a viral vector containing the DNA sequence of CD1d or any other means known in the art to introduce a gene in a cell. Methods for cell transduction are known in the art. The cell line is loaded in culture with the peptide or polypeptide, or with a synthetic peptide encompassing the corresponding sequence. Such synthetic peptides are easily produced by synthesis, using for instance the fmoc solid phase synthesis well known in the art. Efficient presentation of the peptide, polypeptide or corresponding synthetic peptide by the CD1d molecule is then evaluated by measuring the activation of NKT cells. Such cells can be obtained from peripheral blood by, for instance, magnetic sorting and maintained in culture, in the presence of cytokines such as IL-2, IL-15 or IL-7. These methods are described in the art (see for instance Godfrey et al, Nature reviews Immunology 2010, 11: 197-206). Activation of NKT cells is assessed using methods such as evaluation of cytokine production.

Alternatively, peptides actually presented by antigen-presenting cells in CD1d molecules can be eluted and separated by various chromatography methods. Full description of such methodology will be found in Scott et al, Immunity, 12: 711-720, 2000. Said peptides are then sequenced to identify which aminoacid residues are located in P1 and P7.

Alternatively, said synthetic peptides can be loaded on dimers, tetramers or polymers of the CD1d molecule to detect NKT cells specific for such peptide. One possibility is to use fluorescence-labeled tetramers and detection using a fluorescence-activated cell sorting system (facs).

(3) the aminoacid sequences identified as being able to activate NKT cells and, optionally, identified by algorithms, are then modified by either substitution or deletion. In a preferred embodiment, F, W, T, H or Y in positions P1 and/or P7 are replaced by at least one aminoacid different from F, W, T, H, Y. Natural aminoacids can be modified by post-transcriptional modifications or substituted with chemical groups such as methyl groups. In another preferred embodiment, F, W, T, H or Y in positions P1 and/or P7 are replaced by any suitable alternative non-natural aminoacid. Examples of non-natural aminoacid residues are D-aminoacids. In yet another embodiment, F, W, T, H or Y in positions P1 and/or P7 are replaced by at least one aminoacid different from F, W, T, H, Y. In another preferred embodiment, F, W, T, H or Y in position P1 is replaced by at least one aminoacid different from F, W, T, H, Y, by any suitable alternative non-natural aminoacid or by a non-aromatic organic compound. Such aminoacid substitution is obtained using methods well known in the art. In yet a further preferred embodiment, F, W, T, H or Y in position P1 is deleted. In yet another embodiment, F, W, T, H or Y in positions P1 and P7 are deleted. Methods to carry out said deletions are well known in the art. In yet another particular embodiment at least one aminoacid is added within the CD1d binding motif, in any location within the P1 to P7 sequence.

(4) optionally, it may be advantageous to replace hydrophobic aminoacid residues adjacent to the first (P1) and or the last (P7) position by non-hydrophobic residues. Said hydrophobic residues can be located within the flanking regions of the epitope or within the epitope sequence itself at positions P2 or P6). Positions P-2 and P-1, P2 and/or P6, P8 and P9, located at the amino-terminal end or carboxy-terminal end of the epitope, respectively, are advantageously occupied by non-hydrophobic residues, namely aminoacids different from F, W, T, H or Y, which further reduce the affinity of the epitope for CD1d and thereby the capacity of the epitope to activated NKT cells.

(5) NKT cells are then tested for their reactivity with the peptides modified as described in (3). Alternatively, the full-length protein from which the peptide is derived can be produced with the modification of the sequence as described in (3). Various methods can be used to determine whether NKT cells have lost or have reduced their capacity to react to the modified peptide or protein. These methods are known in the art. Proliferation of NKT cells can be assessed by

incorporation of radioactive thymidine, or by evaluating the concentration of cytokines produced in culture medium. Alternatively, NKT cells can be evaluated by ELISPOT using a variety of antibodies driected towards cytokines or molecules associated witht eh cytolytic properties of the cells, such as granzyme B. Alternatively, NKT cells can be evaluated for early signaling events, such as phosphorylation of Fyn or surface activation markers.

In particular, analysis of the sequence of the A1 domain of factor VIII has identified two regions containing motifs enabling factor VIII to bind to the CD1d molecule, according to the methods described above. These 2 regions encompass aminoacid residues 190 to 209 and 309 to 323 and preferably 309 to 316, with sequence:

190-209: QTLHKFILLFAVFDEGKSWH (SEQ ID1)
309-323: FCHISSHQHDGMEAY (SEQ ID2)

Hydrophobic aminoacid residues are underlined and each of the 2 sequences contain 2 CD1d binding motifs, namely:

H193-F199
F195-V201 (P7 is permissive and can accomodate valine)
F309-H315
H317-Y323

According to the present invention medicaments are envisaged for the treatment of diseases wherein administration of factor VIII is required, such as in congenital or acquired deficiency of factor VIII, and in disorders in which it is beneficial to administer factor VIII, such in bleeding disorders associated with acute consumption of factor VIII as observed in septic shock, polytrauma and acute fibrinolysis, or in uncontrolled bleeding associated with cerebral hemorrhage.

The medicament of the invention is usually, though not necessarily, a (pharmaceutical) formulation comprising as active ingredient at least one of the factor VIII molecules of the invention or a gene therapeutic vector capable of expressing said factor VIII molecules. Apart from the active ingredient(s), such formulation will comprise at least one of a (pharmaceutically acceptable) diluent.

In general, administration of factor VIII molecules of the invention prevents activation of the innate immune system, more particularly activation of NKT cells, more particularly the production of cytokines associated with NKT cell activation.

The identification of a NKT-cell epitope in the context of the present invention is known to a person skilled in the art. For instance, peptide sequences isolated from the factor VIII molecule are tested by, for example, NKT cell biology techniques, to determine whether the peptide sequences elicit a NKT cell response. Those peptide sequences found to elicit a NKT cell response are defined as having NKT cell stimulating activity. Human NKT cell stimulating activity can further be tested by culturing NKT cells obtained from an individual sensitized to factor VIII, and determining whether proliferation of NKT cells occurs in response to the peptide/epitope as measured, e.g., by cellular uptake of tritiated thymidine. Stimulation indices for responses by NKT cells to peptides/epitopes can be calculated as the maximum CPM in response to a peptide/epitope divided by the control CPM. A NKT cell stimulation index (S.I.) equal to or greater than two times the background level is considered "positive." Positive results are used to calculate the mean stimulation index for each peptide/epitope for the group of peptides/epitopes tested. An immunogenic peptide having a NKT cell stimulation index of greater than or equal to 2 is considered useful as a candidate to carry out the substitution or deletion of hydrophobic aminoacid residues as described in the present invention.

A peptide or polypeptide of the invention is said to be of reduced capacity to activate NKT cells when the S.I. is less than two times the background level, or when levels of cytokines produced upon stimulation is less than 50% of that produced when stimulation is carried out with the natural peptide or polypeptide sequence, or when the levels of cytolytic agents such as

granzyme B is reduced by at least twofold as compared to peptides or polypeptides of natural sequence.

Soluble CD1d molecules are obtained and made tetrameric by synthesis and/or chemical coupling. The CD1d molecule is purified by affinity chromatography. Soluble CD1d molecules are incubated with a biotin-labeled reference peptide produced according to its strong binding affinity for said CD1d molecule. Peptides to be assessed for CD1d binding are then incubated at different concentrations and their capacity to displace the reference peptide from its CD1d binding site is calculated by addition of neutravidin. Methods can be found in for instance in Texier *et al*., (2000)*J. Immunology* **164**, 3177-3184) for peptides presented by the MHC class II determinants, but the method can easily be applied to CD1d-restricted NKT cell epitopes.

If two or more aminoacid sequences which share an area of overlap in the native peptide or polypeptide sequence are found to have human NKT cell stimulating activity, as determined by T cell biology techniques, mutation or deletion of hydrophobic aminoacid residues may be carried out for residues belonging to one or to both of the sequences.

The route of administration for factor VIII molecules of the present invention may vary according to the indication. Examples are intravenous or subcutaneous injection of factor VIII, but the present invention also covers alternative routes of administration such as intranasal, oral, sublingual, percutaneous or intramuscular.

Factor VIII molecules of the present invention can be produced using methods know in the art for the production of recombinant proteins using expression systems such as bacterial cells, yeast cells, insect cells, plant cells or mammalian cells.

Factor VIII molecules of the invention can be produced by recombinant expression in, e.g., bacterial cells (e.g. *Escherichia coli*), yeast cells (e.g., *Pichia* species, *Hansenula* species, *Saccharomyces* or *Schizosaccharomyces* species), insect cells (e.g. from *Spodoptera frugiperda* or *Trichoplusia ni*), plant cells or mammalian cells (e.g., CHO, COS cells). The construction of the therefore required suitable expression vectors (including further information such as promoter and termination sequences) involves meanwhile standard recombinant DNA

techniques. Recombinantly produced factor VIII molecules of the invention can be derived from a larger precursor protein, e.g., via enzymatic cleavage of enzyme cleavage sites inserted adjacent to the N- and/or C-terminus of the peptide or polypeptide, followed by suitable purification.

The present invention also relates to nucleic acid sequences encoding the factor VIII molecules of the present invention and methods for their use, e.g., for recombinant expression or in gene therapy. In particular, said nucleic acid sequences are capable of expressing factor VIII molecules of the invention.

In gene therapy, recombinant nucleic acid molecules encoding the factor VIII molecules of the present invention can be used as naked DNA or in liposomes or other lipid systems for delivery to target cells. Other methods for the direct transfer of plasmid DNA into cells are well known to those skilled in the art for use in human gene therapy and involve targeting the DNA to receptors on cells by complexing the plasmid DNA to proteins. In its simplest form, gene transfer can be performed by simply injecting minute amounts of DNA into the nucleus of a cell, through a process of microinjection. Once recombinant genes are introduced into a cell, they can be recognized by the cell normal mechanisms for transcription and translation, and a gene product will be expressed. Other methods have also been attempted for introducing DNA into larger numbers of cells. These methods include: transfection, wherein DNA is precipitated with calcium phosphate and taken into cells by pinocytosis; electroporation, wherein cells are exposed to large voltage pulses to introduce holes into the membrane); lipofection/liposome fusion, wherein DNA is packed into lipophilic vesicles which fuse with a target cell; and particle bombardment using DNA bound to small projectiles. Another method for introducing DNA into cells is to couple the DNA to chemically modified proteins. Adenovirus proteins are capable of destabilizing endosomes and enhancing the uptake of DNA into cells. Mixing adenovirus to solutions containing DNA complexes, or the binding of DNA to polylysine covalently attached to adenovirus using protein crosslinking agents substantially improves the uptake and expression of the recombinant gene. Adeno-associated virus vectors may also be used for gene delivery. As used herein, "gene transfer" means the process of introducing a foreign nucleic acid molecule into a cell, which is commonly performed to enable the

expression of a particular product encoded by the gene. The said product may include a protein, polypeptide, anti-sense DNA or RNA, or enzymatically active RNA. Gene transfer can be performed in cultured cells or by direct administration into mammals. In another embodiment, a vector comprising a nucleic acid molecule sequence encoding a factor VIII molecule according to the invention is provided. In particular embodiments, the vector is generated such that the nucleic acid molecule sequence is expressed only in a specific tissue. Methods of achieving tissue-specific gene expression are well known in the art, e.g., by placing the sequence encoding a factor VIII molecule of the invention under control of a promoter, which directs expression of said molecule specifically in one or more tissue(s) or organ(s). Expression vectors derived from viruses such as retroviruses, vaccinia virus, adenovirus, adeno-associated virus, herpes viruses, RNA viruses or bovine papilloma virus, may be used for delivery of nucleotide sequences (e.g., cDNA) encoding peptides, homologues or derivatives thereof according to the invention into the targeted tissues or cell population. Methods which are well known to those skilled in the art can be used to construct recombinant viral vectors containing such coding sequences. Alternatively, engineered cells containing a nucleic acid molecule coding for a peptide or polypeptide according to the invention may be used in gene therapy.

Factor VIII of the present invention can be modified by methods known in the art.

Factor VIII molecules can encompass the entire aminoacid sequence of factor VIII or only parts of it. One example is provided by B domain deleted factor VIII molecules. The B domain is dispensable for the function of factor VIII and can therefore be deleted without affecting factor VIII function. The a2 and a3 domains are usually linked by aminoacid sequence which can be artificial or can represent sequences from the B domain itself. Factor VIII molecules can be modified by addition and/or substitution of of aminoacids so as to increase factor VIII stability by, for instance, reducing the decoy rate of the A2 domain, or by increasing factor VIII resistance to proteolytic enzymes. Factor VIII molecules can be stabilized by coupling to Fcgamma part of antibodies, for instance to increase its recycling trough the FcRn receptor. Factor VIII can be stabilized by reducing its degradation using polyethyleneglycol residues (PEG derivatives) or alternative chemical subsitution. All these modifications are considered as within the scope of the present invention.

The prior art (Swaroop et al., The Journal of Biological Chemistry, vol 272, pp 24121-24124, 1997; Cerullo et al., Molecular Therapy, vol 15, pp 2080-2087, 2007) has identified that mutation of F309 (SEQ ID2) increases the rate of production of factor VIII molecules by cells transfected with a factor VIII construct. Cerullo et al. observed a non-significant reduction of the production of inhibitor antibodies in factor VIII KO mice treated with the F309 mutant, teaching away the one skilled in the art from the use of such mutant for reducing factor VIII immunogenicity. Moreover, in said prior art, there is no mention that F309 could be part of a CD1d binding motif.

The medicament of the invention is usually, but not necessarily a (pharmaceutical) formulation comprising as active ingredient at least one factor VIII molecule of the invention, a gene therapeutic vector capable of expressing said factor VIII molecule. Apart from the active ingredient(s), such formulation will comprise at least one of a (pharmaceutically acceptable) diluent. Typically, pharmaceutically acceptable compounds can be found in, e.g., a Pharmacopeia handbook (e.g. US-, European- or International Pharmacopeia). The medicament or pharmaceutical composition of the invention normally comprises a (prophylactically or therapeutically) effective amount of the active ingredient(s) wherein the effectiveness is relative to the condition or disorder to be prevented or treated.

The medicament or pharmaceutical composition of the invention may, in a prefered embodiment, need to be administered to a subject in need as part of a prophylactic or therapeutic regimen comprising multiple administrations of said medicament or composition. Said multiple administrations usually occur sequentially and the time-interval between two administrations can vary and will be adjusted to the nature of the active ingredient and the nature of the condition to be prevented or treated. The amount of active ingredient given to a subject in need of a single administration can also vary and will depend on factors such as the physical status of the subject (as for instance weight and age), the status of the condition to be prevented or treated, and the experience of the treating doctor, physician or nurse.

The term “diluents” refers for instance to physiological saline solutions. The term "pharmaceutically acceptable carrier" means any material or substance with which the active ingredient is formulated in order to facilitate its application or dissemination to the locus to be

treated, for instance by dissolving, dispersing or diffusing the said composition, and/or to facilitate its storage, transport or handling without impairing its effectiveness. They include any and all solvents, dispersion media, coatings, antibacterial and antifungal agents (for example phenol, sorbic acid, chlorobutanol), isotonic agents (such as sugars or sodium chloride) and the like. Additional ingredients may be included in order to control the duration of action of the active ingredient in the composition. The pharmaceutically acceptable carrier may be a solid or a liquid or a gas which has been compressed to form a liquid, i.e. the compositions of this invention can suitably be used as concentrates, emulsions, solutions, granulates, dusts, sprays, aerosols, suspensions, ointments, creams, tablets, pellets or powders. Suitable pharmaceutical carriers for use in said pharmaceutical compositions and their formulation are well known to those skilled in the art, and there is no particular restriction to their selection within the present invention. They may also include additives such as wetting agents, dispersing agents, stickers, adhesives, emulsifying agents, solvents, coatings, antibacterial and antifungal agents (for example phenol, sorbic acid, chlorobutanol), isotonic agents (such as sugars or sodium chloride) and the like, provided the same are consistent with pharmaceutical practice, i.e. carriers and additives which do not create permanent damage to mammals. The pharmaceutical compositions of the present invention may be prepared in any known manner, for instance by homogeneously mixing, coating and/or grinding the active ingredients, in a one-step or multi-steps procedure, with the selected carrier material and, where appropriate, the other additives such as surface-active agents. They may also be prepared by micronisation, for instance in view to obtain them in the form of microspheres usually having a diameter of about 1 to 10 µm, namely for the manufacture of microcapsules for controlled or sustained release of the active ingredients.

The formulations may conveniently be presented in unit dosage form and may be prepared by any of the methods well known in the art of pharmacy.

The following examples are provided here to illustrate the invention. There is however no intention to limit the invention to such examples.

Example 1:

<u>Binding of peptide of SEQ ID1 to CD1d tetramers</u>

A peptide encompassing SEQ ID1 was obtained by chemical synthesis. This peptide was used to load CD1d tetramers (ProImmune) by overnight incubation.

NKT cells were prepared from the spleen of naïve mice by depletion of all CD4(-) cells using magnetic beads.

CD4+ cells were then incubated with CD1d tetramers loaded by peptide of SEQ ID1 (P28 WT in Figure 1), which corresponds to aminoacid sequence 190 to 209.

Figure 1 shows that ± 1% of CD4+ T cells were detected. Further, peptide of SEQ ID1 was separated into 2 parts and synthetic peptides covering the sequence 190-200 (SEQ ID3, P28 A in Figure 1) and 200-210 (SEQ ID4, P28 B in Figure 1) were produced.

Sequence of peptide of SEQ ID3 is:

QTLHKFILLFA (corresponding to aminoacid sequence 190 to 200)

Sequence of peptide of SEQ ID4 is:

AVFDEGKSWHS (corresponding to aminoacid sequence 200 to 210)

The Figure indicates that a major CD1d binding motif is located in SEQ ID3, and limited though significant % of NKT cells were detected by the peptide of SEQ ID4.

It was therefore concluded that a major CD1d binding motif was located in peptide of SEQ ID3.

Example 2:

Activation of NKT cells by immunization with JAWS2 cells loaded with peptide of SEQ ID1

JAWS2 cells express CD1d but not MHC class II determinants. These cells were used to show that the presentation of peptide of SEQ ID1 can occur via CD1d.

JAWS2 cells were incubated 2 h at 37°C with peptide of SEQ ID1 (10 µg/ml) and thoroughly washed twice. Cells were then treated with mitomycin to block cell division and washed 4 times to eliminate mitomycin. A cell suspension containing $2x10^6$ cells in physiological serum was injected by the intraperitoneal route in each of a series of 3 naïve factor VIII KO mice. As a control, 3 naïve factor VIII KO mice received the same number of JAWS2 cells which had not been incubated with peptide of SEQ ID1.

Five days after IP injection, the mice were sacrificed and their spleen prepared as above using magnetic beads to eliminate all CD4(-) cells.

CD4+ cells were then incubated with tetramers loaded with peptide of SEQ ID1.

Figure 2 shows that a significant proportion of NKT cells (8%) present in the natural repertoire are specific for peptide of SEQ ID1 and that such proportion is doubled (16%) when peptide of SEQ ID1 is presented by JAWS2 cells.

The specificity of NKT cell detection is shown by the lack of NKT detection with unloaded tetramers as well as when tetramers were loaded with a peptide unrelated to peptide of SEQ ID1.

It was therefore concluded that presentation of peptide of SEQ ID1 occurred via CD1d presentation and that this presentation was sufficient as to bind and activate NKT cells.

Example 3:

Administration of mutated factor VIII reduces the formation of antibodies to factor VIII

To determine whether mutation aimed at eliminating CD1d binding motifs in factor VIII could reduce the concentration of anti-factor VIII antibodies, wildtype or mutated factor VIII were cloned in the plasmid pGC5AM-EN. Mutations in positions F309 and H315, each time into a alanine, were introduced in the sequence of factor VIII using PCR and the splicing by overlap extension (SOE-PCR) technology.

The plasmids containing either the native or the mutated sequence were checked by sequencing and prepared by maxiprep.

Plasmids (100 µg in 2 ml) were directly administered into naïve factor VIII KO C57BL/6 mice (3 mice per group) using the hydrodynamic pressure method (injection made in less than 7 seconds), known in the art to direct plasmids essentially to the liver. Control mice were injected using the same method but with naked plasmid (n=3).

A total of 3 injections were made at intervals of 10 days.

Ten days after the last injection, plasma concentrations of antibodies to factor VIII and the concentration of antibodies inhibiting the function of factor VIII were measured by ELISA and chromogenic assay, respectively.

Figure 3a indicates that a 3.6-fold reduction of antibodies was observed in mice injected with the factor VIII mutant F309A-H315A. Figure 3b shows a 3.8-fold reduction of antibodies inhibiting the function of factor VIII.

These data showed that elimination of a single CD1d binding motif in the factor VIII molecule is sufficient to significanlty reduced the concentration of specific antibodies, including those inhibiting the function of factor VIII.

Example 4:

Increased expression of CD1d on human antigen-presenting cells upon incubation with a peptide containing a CD1d-binding motif

To determine whether human antigen-presenting cells had the capacity to process and present a peptide epitope in the context of the CD1d molecule, the human macrophage cell line U937 was used. Such cells do not express class II major histocompatiblity complexes and are used to assess presentation by CD1d.

The percentage of resting U937 cells expressing CD1d is low as detected with a specific anti-CD1d antibody. It was reasoned that, if U937 cells were incubated with a peptide having the sequence motif enabling it to bind to CD1d, then this should be detectable by increased expression of CD1d at cell surface. As observed for peptides encompassing MHC class II epitopes, the binding of a peptide stabilizes the conformation of the molecule (class II, or CD1d in the present case), allowing the complex to be anchored at cell surface and reducing its intracellular recycling.

U937 cells ($7x10^5$ cells) were incubated for 24h at 37°C with 5 µg of peptide encompassing CD1d binding motifs or controls. The cells were then washed and incubated with fluorescence-labeled antibodies specific to CD1d and the number of positive cells evaluated using a FACS system.

Figure 4 shows that the percentage of cells expressing CD1d increases from 6% in control experiments to 13% when peptides containing CD1d-binding sequences were used. Data shown as histograms are means of triplicate measurements, with asterisk identifying results significantly higher than control values ($p<0.05$).

Controls include (from left to right) unloaded U937, cells incubated with alpha-gal-ceramide and a conventional class II-restricted epitope (MHCII-MOG). The experiment includes sequences of factor VIII of either human (ID SEQ5) or mouse (ID SEQ 6) origin corresponding to aminoacids 188-204 of the factor VIII sequence.

It is therefore concluded that human antigen-presenting cells stabilize complexes of peptides and CD1d at their surface when incubated with said peptides.

Example 5:

Human peripheral blood mononucleated cells (PBMC) contain NKT cells specific for CD1d-bound peptidic epitopes

In order to establish whether human PBMC contained cells reacting with a CD1d-binding peptide epitope, invariant NKT (iNKT) cells were prepared from a buffy coat using magnetic beads coated with an antibody specific to the Valpha24-Jalpha18 chain of the T cell receptor (so-called invariant chain).

Said human iNKT cells (10^5/condition) were then incubated with mitomycine-C treated U937 cells (Ratio 1:1) loaded with 5 µg of either peptide encompassing aminoacid residues 188-204 of human factor VIII (ID SEQ 5) or with control peptide (MHCII-MOG). Incubation was carried out for 2 weeks at 37°C in RPMI containing 10% of fetal calf serum and 50 U/ml of human recombinant IL-2.

Culture plates were examined by eye for the presence of cell clusters. It is observed that clumps of cells form with U937 loaded with peptide of ID SEQ 5 to the same extent that with alpha-

gal-ceramide, but not with control peptide (MHCII-MOG). Figure 5 illustrates the average of three microscopic field count of this observation (minimum 10 cells/ cluster).

It is therefore concluded that human peripheral cell repertoire contains cells defined as invariant chain NKT cells reacting with a peptide presented by CD1d.

Example 6:

Flanking residues located outside of the CD1d binding cleft are important for efficient cell surface presentation

The experiment shown in Example 1 indicates that a peptide of SEQ ID 3, corresponding to human factor VIII aminoacids 190-200, binds to CD1d tetramers and allows the detection of NKT cells, indicating that this sequence contained the minimum binding motif for CD1d.
To determine whether this motif was sufficient for efficient presentation by cells, the experiment reported in example 4 was repeated with peptide of SEQ ID 3.

Figure 6 shows that peptide of SEQ ID 3 did not increase expression of CD1d at the surface of U937 cells, in contrast to peptides of SEQ ID 5 shown in Figure 4.

It is therefore concluded that an efficient in vivo loading of a peptide containing a CD1d-binding motif requires the presence of flanking residues located outside of the CD1d cleft.

Example 7:

NKT cells specific for CD1d-binding factor VIII epitope belong to both the CD4+ and CD8+ lineages

To determine the cell lineage to which NKT cells belonged, an experiment was performed as described in Example 2. Thus, JAWS2 cells were loaded with either peptide of SEQ ID 3, B-domain-deleted factor VIII, alpha-gal-ceramide or kept unloaded before intraperitoneal (IP)

injection in factor VIII KO mice ($2x10^6$ cells per mouse). Five days after intraperitoneal injections, the mice were sacrificed and the splenocytes prepared. Cell suspensions were then reacted with CD1d tetramers unloaded or loaded with peptide of SEQ ID3 or with alpha-gal-ceramide.

For faccs analysis, cells binding CD1d tetramers were labeled with DX5- and CD160- specific antibodies and either anti-CD4 or anti-CD8 antibodies. The table summarizes the results.

			DX5/CD160	Number of cells ($x10^3$)	
			Tetramers	CD4+	CD8+
1	JAWS2	(-)	(-)	0.3	0.1
2			Alpha-gal-cer	1.2	1.3
3			Peptide SEQ ID3	**39**	**3.5**
4	JAWS2	Peptide SEQ ID3	(-)	0.2	0.1
5			Alpha-gal-cer	2.2	0.8
6			Peptide SEQ ID3	**47**	**4.1**
7	JAWS2	Factor VIII	(-)	0.1	0.5
8			Alpha-gal-cer	1.9	1.4
9			Peptide SEQ ID3	**62**	**11**
10	JAWS2	Alpha-gal-cer	(-)	0.1	0
11			Alpha-gal-cer	2.3	1.8
12			Peptide SEQ ID3	**46**	**1.9**

These experiments show that

- the natural repertoire of NKT cells contains a significant number of cells reacting to peptide of ID SEQ 3 in both the CD4+ and CD8+ lineages (line 3)
- this population of cells can be further expanded by immunization with peptide of SEQ ID3, again in both CD4+ and CD8+ lineages (line 6)
- immunization with factor VIII is even more efficient in expanding these cell populations (line 9)

• immunization with alpha-gal-ceramide slightly increases the number of CD4+ T cells specific for peptide of SEQ ID3, but not the number of CD8+ T cells

Taken together, these results indicate that immunization with factor VIII elicits an expansion of cells belonging to the NKT lineage of both the CD4+ and CD8+ phenotype.

Sequences

ID1 QTLHKFILLFAVFDEGKSWH (human 190-209)
ID2 FCHISSHQHDGMEAY (human 309-323)
ID3 QTLHKFILLFA (human 190-200)
ID4 AVFDEGKSWHS (human 200-210)
ID5 KTQTLHKFILLFAVFDE (human 188-204)
ID6 RTQMLYQFVLLFAVFDE (mouse 188-204)

Claims

1. A factor VIII molecule with a domain structure A1-a1-A2-a2-B-a3-A3-C1-C2, in which A1, A2, B, A3, C1 and C2 represent domains and a1, a2 and a3 acidic regions linking said domains said factor VIII molecule having a reduced capacity to activate NKT cells is obtainable by:

a. identification of at least one NKT cell epitope wherein said epitope comprises hydrophobic aminoacid residues in position P1 and/or P7

b. modification of said epitope(s) by eliminating at least one hydrophobic aminoacid residue in position P1 and/or P7, substituting at least one hydrophobic aminoacid residue in position P1 and/or P7 with a non-hydrophobic residue, or adding a non-hydrophobic residue in position P1 and/or P7.

2. The factor VIII molecule according to claim 1, characterized in that said hydrophobic residues in position P1 and/or P7 are F, W, T, H, Y.

3. The factor VIII molecule according to any previous claim characterized in that said NKT cell epitope comprises an aliphatic residue in P4 and said aliphatic residue is I, L, M.

4. The factor VIII molecule according to any previous claims characterized in that said NKT cell epitope motif is [FWTHY]-X_2X_3-[ILMV]-X_5X_6-[FWTHY].

5. The factor VIII molecule according to any previous claims, characterized in that at least one F, W, T, H, Y in position P1 and/or P7 is substituted by at least one any natural aminoacid, non-natural aminoacid or non-aromatic aminoacid compounds wherein said aminoacid is different from F, W, T, H, Y.

6. The factor VIII molecule according to any previous claims, characterized in that at least one F, W, T, H, Y in position P-1 and/or P-2 and/or P8 and/or P9 is substituted with a non-hydrophobic residue.

7. The factor VIII molecule according to any previous claims comprising at least one hydrophobic aminoacid residues located at positions P-2, P-1, P2, P6, P8 and/or P9, adjacent to the P1 and/or the P7 positions, characterized in that said at least one hydrophobic aminoacid residues are replaced by non-hydrophobic residues.

8. The factor VIII molecule according to claim 7 characterized in that said at least one hydrophobic aminoacid residues located at positions P-2, P-1, P2, P6, P8 and/or P9 are different from F, W, T, H or Y.

9. The factor VIII molecule according to claim 1 characterized in that said NKT cells belong to the CD4+ or CD8+ lineage.

10. The factor VIII molecule according to any of the claims 1 to 9 characterized in that NKT cell epitopes are located within the A1 domain of factor VIII.

11. The factor VIII molecule according to claim 10 characterized in that the NKT cell epitopes are located within the aminoacid sequence 190 to 209 and/or 309 to 316.

12. The factor VIII molecule according to claims 1 to 11 characterized in that said molecule is further modified by deletion of the B domain and/or by addition or substitution of aminoacid(s).

13. The factor VIII molecule according to claims 1 to 12 characterized in that said molecule is produced by recombinant expression.

14. Factor VIII molecules as described in claims 1 to 13 claims for use as a medicament.

15. Factor VIII molecules as described in claim 14 for administration of said molecules in the form of proteins or by gene therapy.

16. Factor VIII molecules as described in claim 15 for use as a medicament in the treatment of congenital or acquired haemophilia A.

17. Factor VIII molecules as described in claim 15 for use as a medicament in the treatment of patients with bleeding disorders such as in septic shock, acute fibrinolysis, polytrauma or cerebral haemorrhage.

18. Method to obtain a factor VIII molecule with reduced capacity to activate NKT cells comprising the steps of:

a. identification of at least one NKT cell epitope wherein said epitope comprises hydrophobic aminoacid residues in position P1 and/or P7

b. modification of said epitope(s) by eliminating at least one hydrophobic aminoacid residue in position P1 and/or P7, substituting at least one hydrophobic aminoacid residue in position P1 and/or P7 with a non-hydrophobic residue or adding a non-hydrophobic residue in position P1 and/or P7.

19. The method of claim 18 wherein said NKT cell epitope is [FWTHY]-X_2X_3-[ILMV]-X_5X_6-[FWTHY].

20. Method to reduce immunigenicity of a factor VIII molecule comprising the steps of:

a. identification of at least one NKT cell epitope wherein said epitope comprises hydrophobic aminoacid residues in position P1 and/or P7

b. modification of said epitope(s) by eliminating at least one hydrophobic aminoacid residue in position P1 and/or P7, substituting at least one hydrophobic aminoacid residue in position P1 and/or P7 with a non-hydrophobic residue or adding a non-hydrophobic residue in position P1 and/or P7.

21. The method of claim 20 wherein said NKT cell epitope is [FWTHY]-X_2X_3-[ILMV]-X_5X_6-[FWTHY].

22. The method of claim 20 or 21 wherein at least one hydrophobic aminoacid residues located at positions P-2, P-1, P2, P6, P8 and/or P9, adjacent to the P1 and/or the P7 positions is replaced by non-hydrophobic residues.

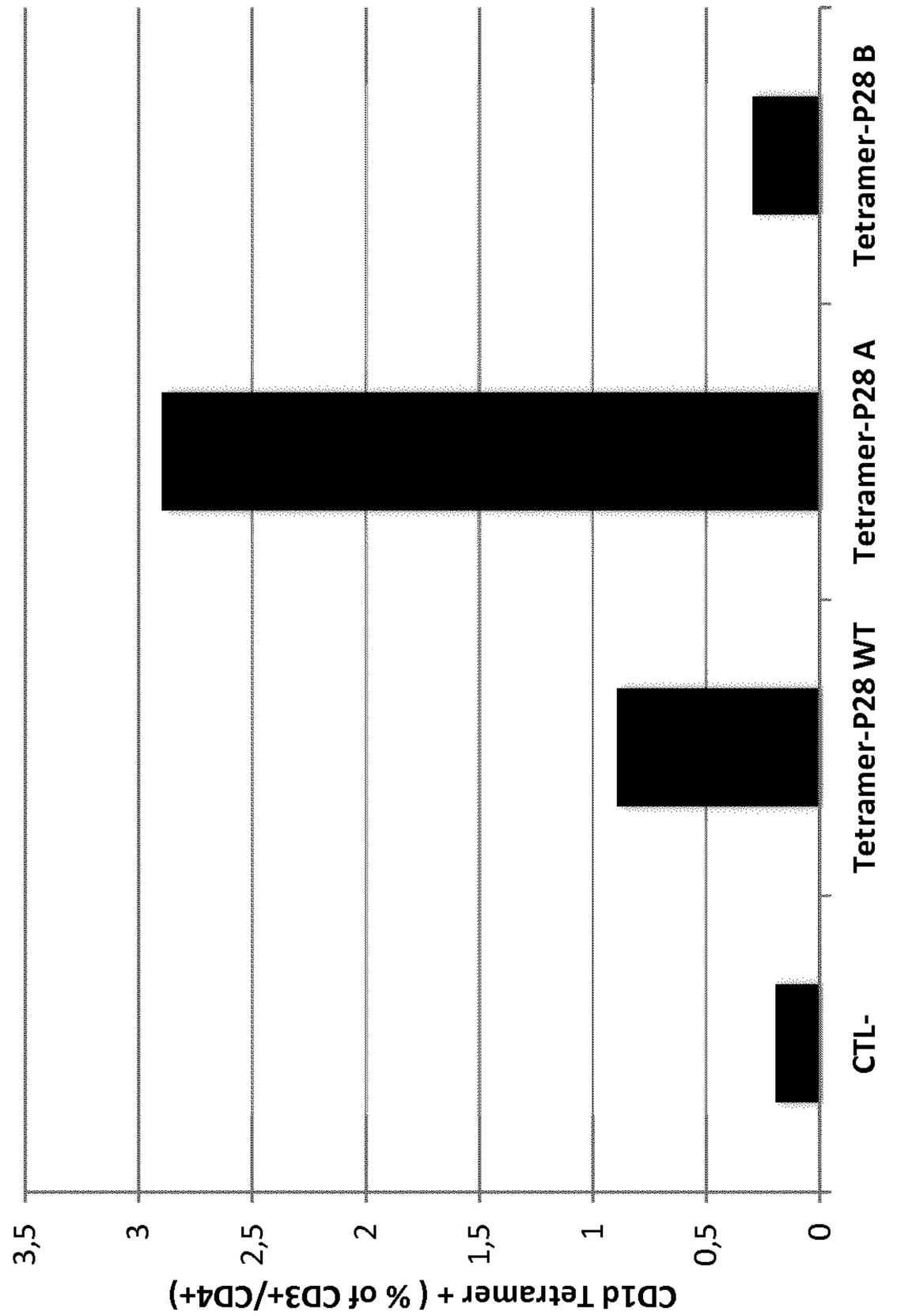
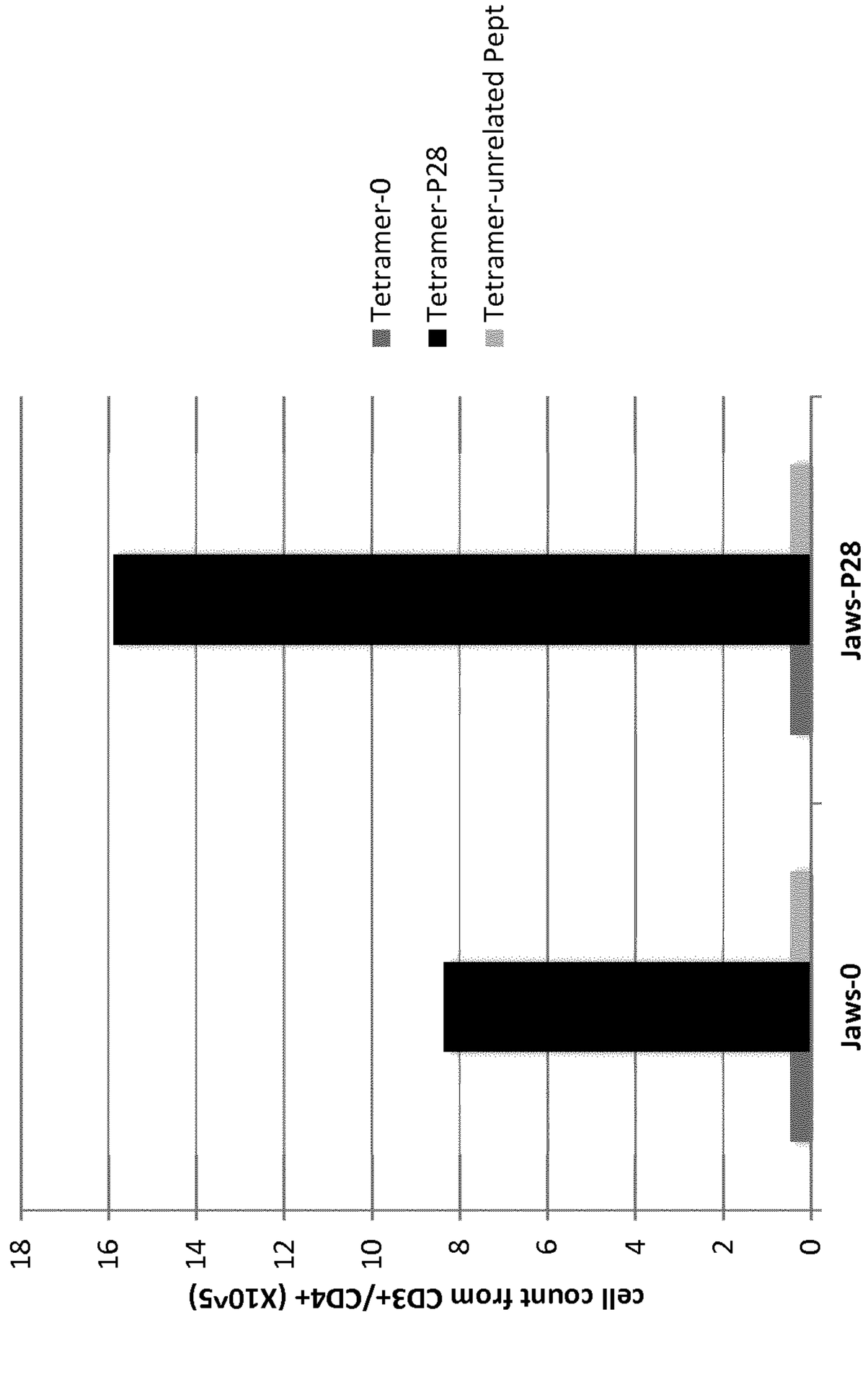

CD1d Tetramer + (% of CD3+/CD4+)
3,5
3
2,5
2
1,5
1
0,5
0
CTL-
Tetramer-P28 WT
Tetramer-P28 A
Tetramer-P28 B

Figure 1


Tetramer-0
Tetramer-P28
Tetramer-unrelated Pept
Jaws-P28
Jaws-0
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4
6
8
10
12
14
16
18

Figure 2

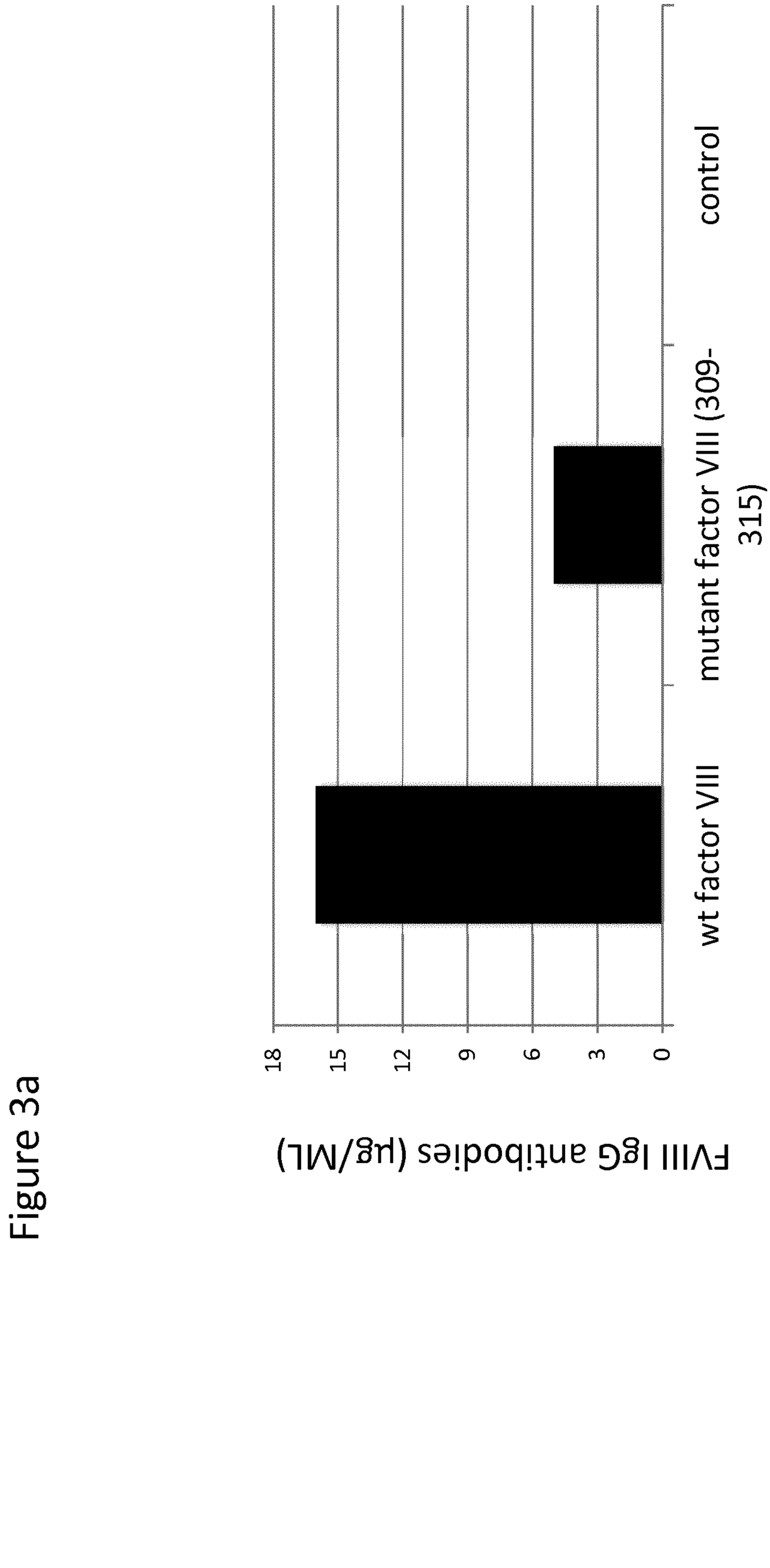

wt factor VIII
mutant factor VIII (309-315)
control
FVIII IgG antibodies (µg/ML)
0
3
6
9
12
15
18

Figure 3a

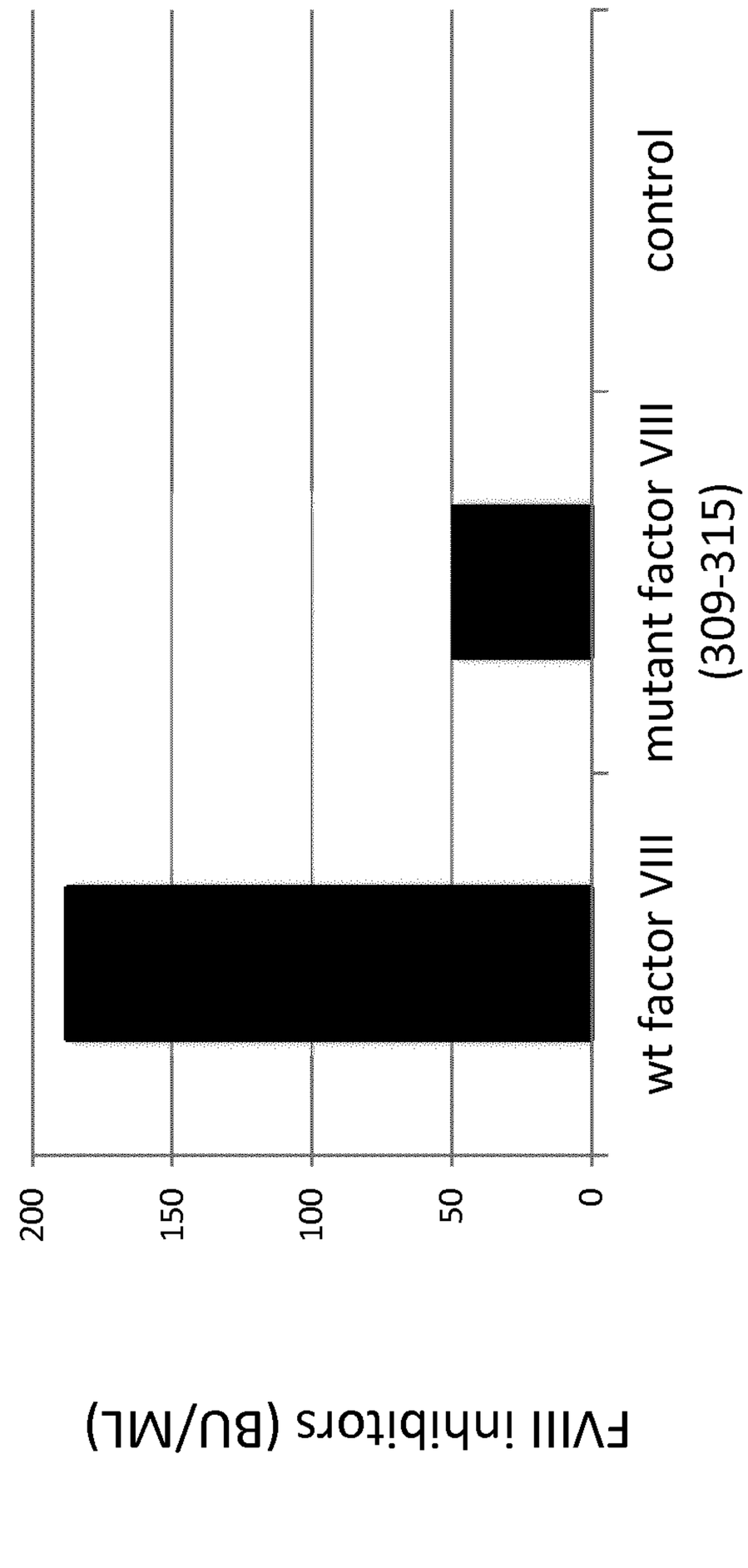
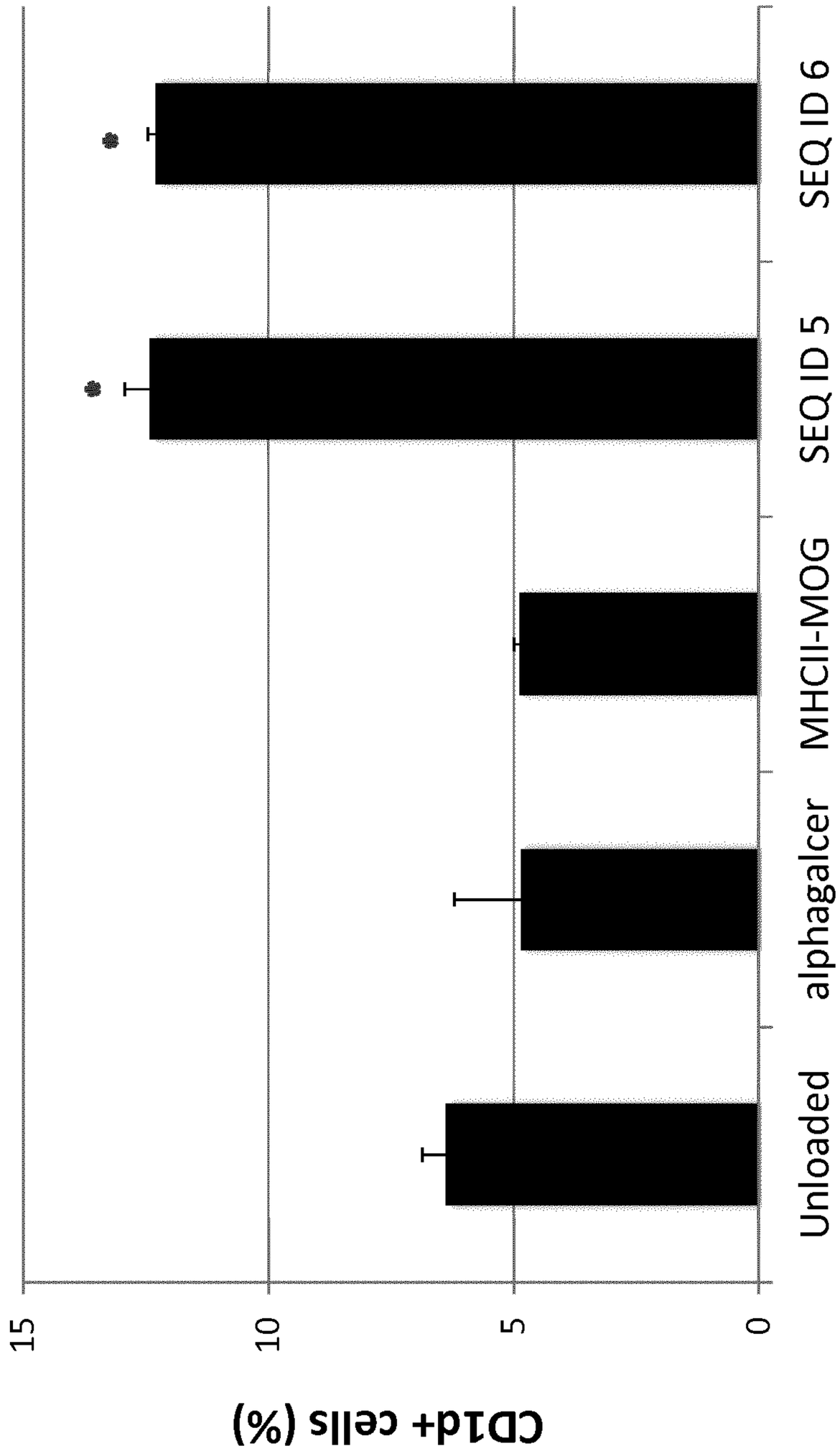

FVIII inhibitors (BU/ML)
200
150
100
50
0
wt factor VIII
mutant factor VIII (309-315)
control

Figure 3b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0
5
10
15
Unloaded
alphagalcer
MHCII-MOG
SEQ ID 5
SEQ ID 6

Figure 4

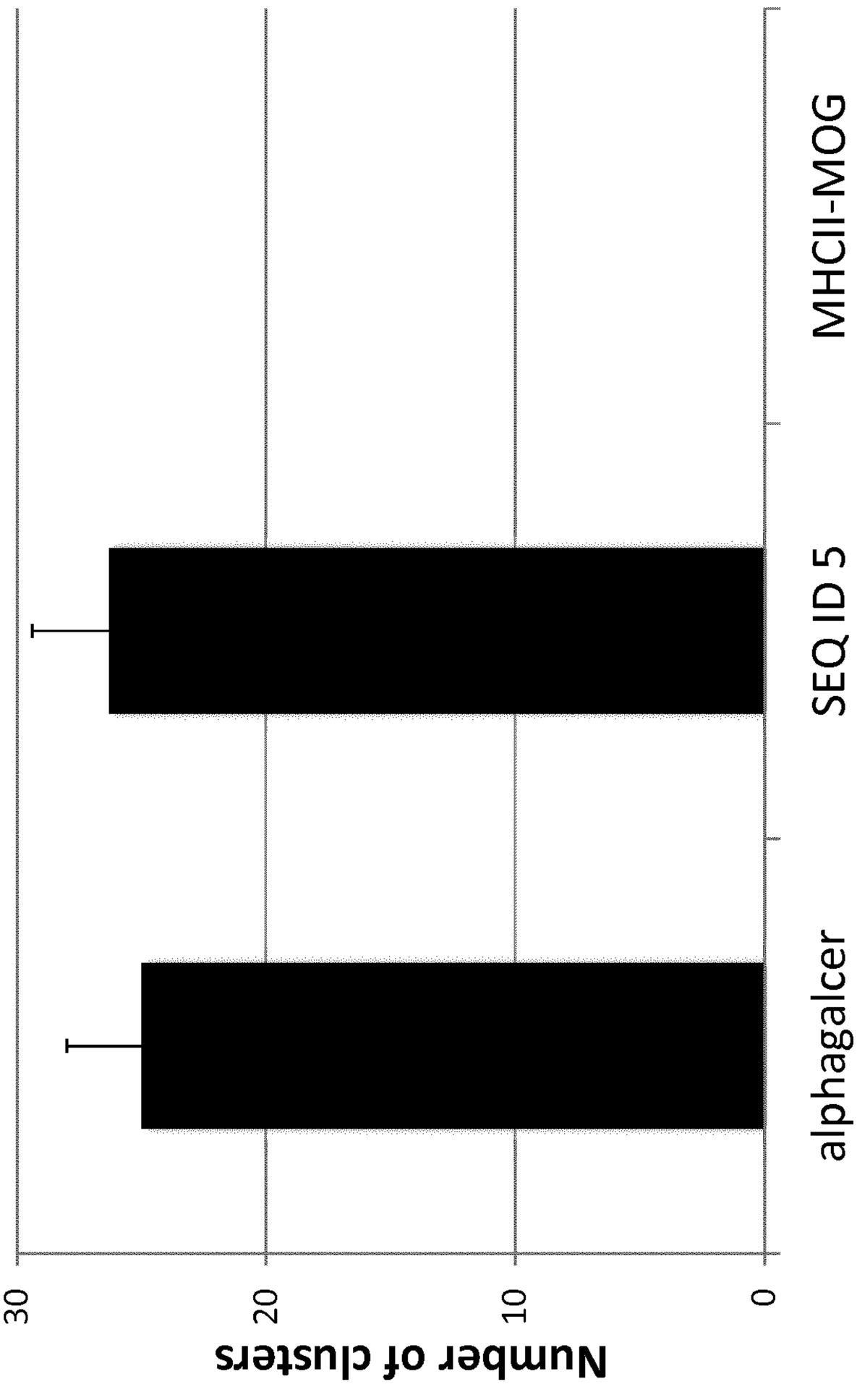


Figure 5

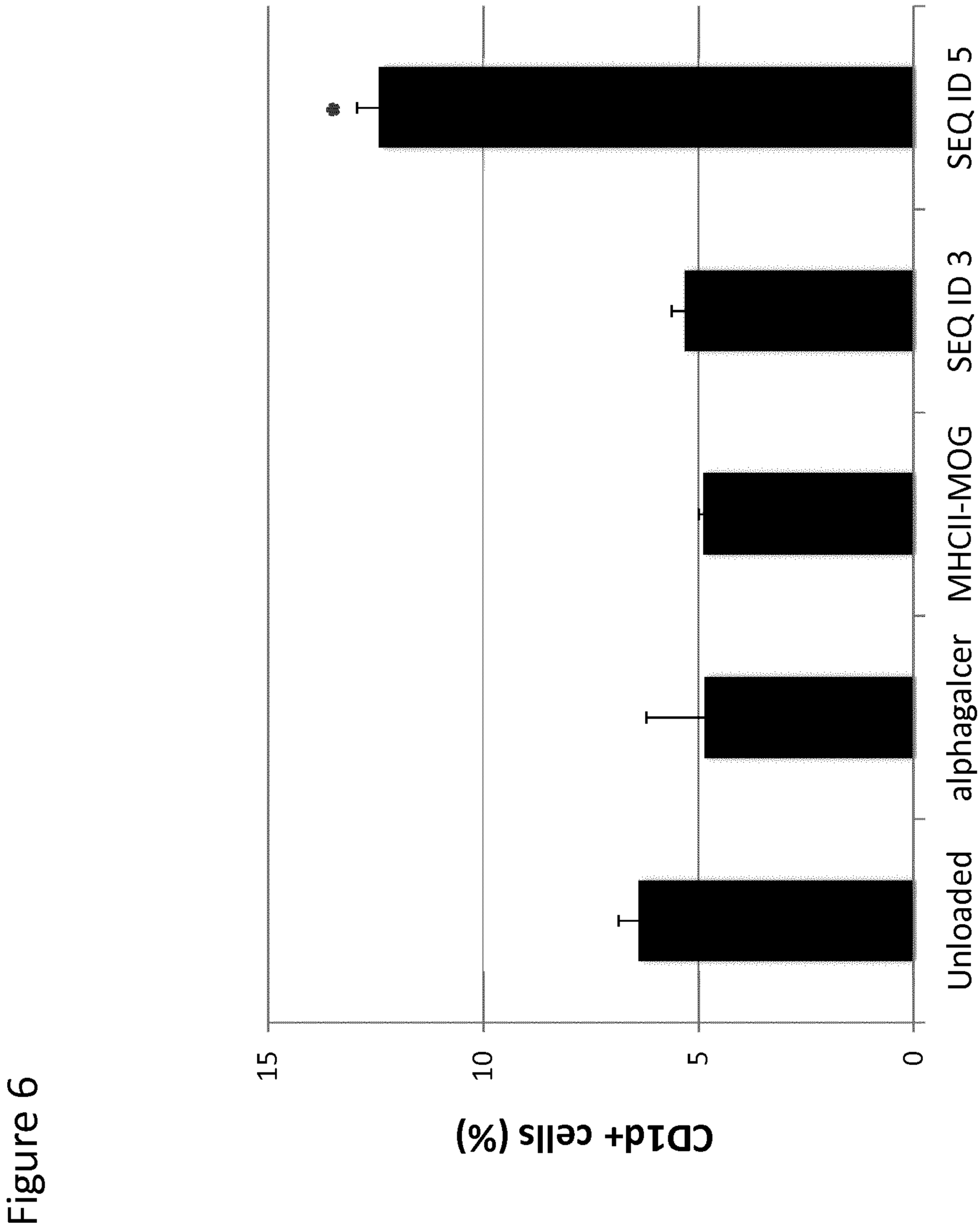
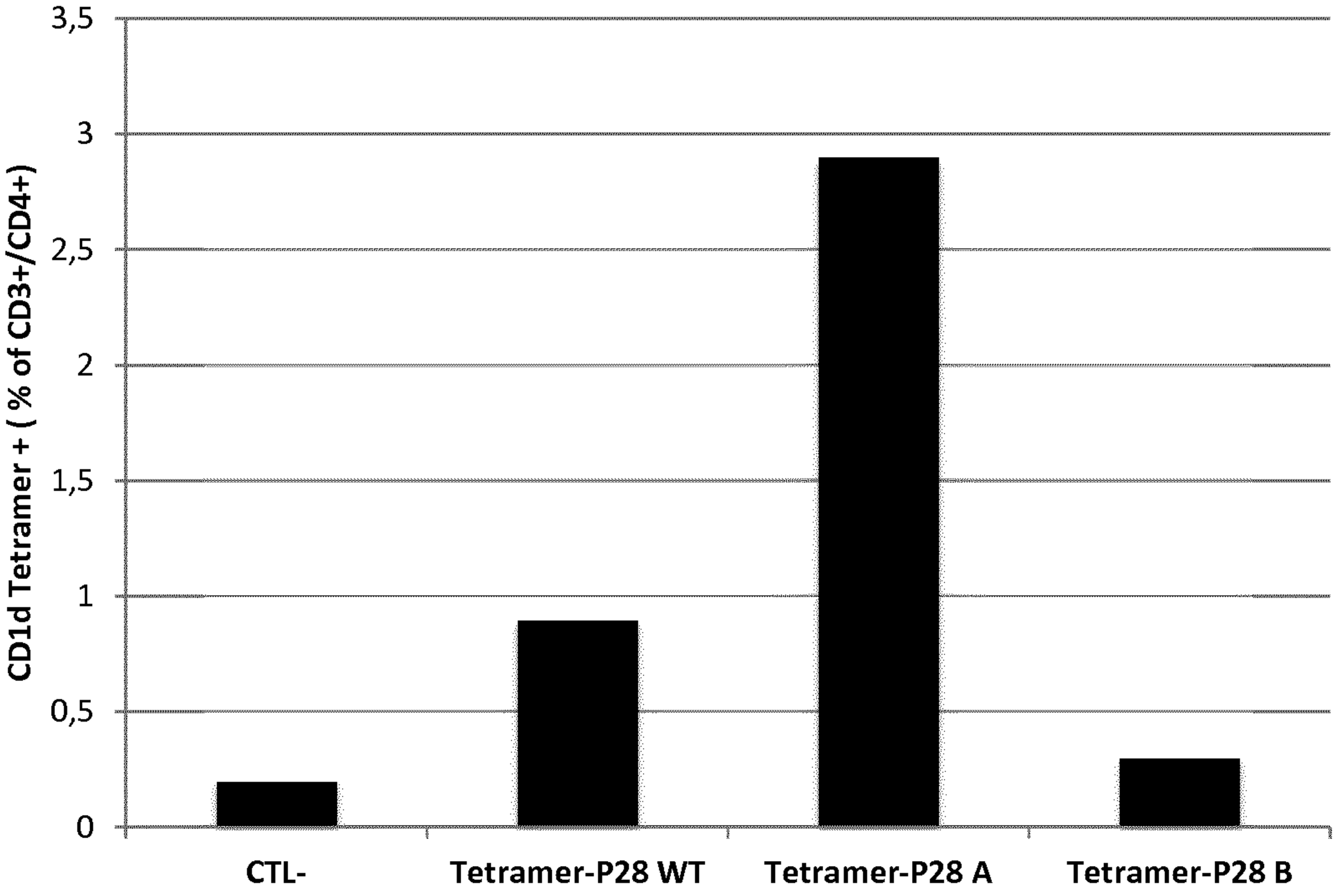

CD1d+ cells (%)
15
10
5
0
Unloaded
alphagalcer
MHCII-MOG
SEQ ID 3
SEQ ID 5

Figure 6

Figure 1


CD1d Tetramer + (% of CD3+/CD4+)
3,5
3
2,5
2
1,5
1
0,5
0
CTL-
Tetramer-P28 WT
Tetramer-P28 A
Tetramer-P28 B