HUMANIZED ANTI CXCR4 ANTIBODIES FOR THE TREATMENT OF CANCER

The present invention relates to a novel antibody, in particular a humanized monoclonal antibody, able to bind specifically to chemokine receptors (CXCR) as well as the amino and nucleic acid sequences coding for such an antibody. From one aspect, the invention relates to a novel antibody, derived compounds or functional fragments, able to bind specifically to the CXCR4 and having strong anti-tumor activities. The invention also comprises the use of such an antibody as a drug for the preventive and/or therapeutic treatment of cancer, as well as in the procedures or kits related to cancer diagnosis. Finally, the invention comprises compositions comprising such an antibody in combination or conjugation with other anti-cancer compound(s), such as antibodies, toxins, cytotoxic/cytostatic, and the use of same for the prevention and/or treatment of certain cancers.

Chemokines are small, secreted peptides that control the migration of leukocytes along a chemical gradient of ligand, known as chemokine gradient, especially during immune reactions (Zlotnick A. et al., 2000). They are divided into two major subfamilies, CC and CXC, based on the position of their NH_2-terminal cysteine residues, and bind to G protein coupled receptors, whose two major sub families are designated CCR and CXCR. More than 50 human chemokines and 18 chemokine receptors have been discovered so far.

Many cancers have a complex chemokine network that influences the immune-cell infiltration of tumor, as well as tumor cell growth, survival, migration and angiogenesis. Immune cells, endothelial cells and tumor cells themselves express chemokine receptors and can respond to chemokine gradients. Studies of human cancer biopsy samples and mouse cancer models show that cancer cell chemokine-receptor expression is associated with increase metastatic capacity. Malignant cells from different cancer types have different profiles of chemokine-receptor expression, but Chemokine receptor 4 (CXCR4) is most commonly found. Cells from at least 23 different types of human cancers of epithelial, mesenchymal and haematopoietic origin express CXCR4 receptor (Balkwill F. et al., 2004).

Chemokine receptor 4 (also known as fusin, CD184, LESTR or HUMSTR) exists as two isoforms comprising 352 or 360 amino acids. Residue Asn11 is glycosylated, residue Tyr21 is modified by the addition of a sulfate group and Cys 109 and 186 are bond with a disulfide bridge on the extracellular part of the receptor (Juarez J. et al., 2004).

This receptor is expressed by different kind of normal tissues, naïve, non-memory T-cells, regulatory T cells, B-cells, neutrophils, endothelial cells, primary monocytes, dendritic cells, Natural Killer cells, CD34+ hematopoietic stem cells and at a low level in heart, colon, liver, kidneys and brain. CXCR4 plays a key role in leukocytes trafficking, B cell lymphopoiesis and myelopoiesis.

CXCR4 receptor is over-expressed in a large number of cancers including but not limited to colon (Ottaiano A. et al., 2004), breast (Kato M. et al., 2003), prostate (Sun Y.X. et al., 2003), lungs [small-cell- and non-small-cell- carcinoma (Phillips R.J. et al., 2003)], ovary (Scotton C.J. et al., 2002), pancreas (Koshiba T. et al., 2000), kidneys, brain (Barbero S et al., 2002), glioblastoma and lymphomas.

The unique ligand of CXCR4 receptor described so far is the Stromal-cell-Derived Factor-1 (SDF-1) or CXCL12. SDF-1 is secreted in large amount in lymph nodes, bone marrow, liver, lungs and to a less extent by kidneys, brain and skin. CXCR4 is also recognized by an antagonistic chemokine, the viral macrophage inflammatory protein II (vMIP-II) encoded by human herpesvirus type III.

CXCR4/SDF-1 axis plays a key role in cancer and is implicated directly in migration, invasion leading to metastases. Indeed, cancer cells express CXCR4 receptor, they migrate and enter the systemic circulation. Then cancer cells are arrested in vascular beds in organs that produce high levels of SDF-1 where they proliferate, induce angiogenesis and form metastatic tumors (Murphy PM., 2001). This axis is also involved in cell proliferation via activation of Extracellular-signal-Regulated Kinase (ERK) pathway (Barbero S. et al., 2003) and angiogenesis (Romagnani P., 2004). Indeed, CXCR4 receptor and its ligand SDF-1 clearly promote angiogenesis by stimulating VEGF-A expression which in turns increases expression of CXCR4/SDF-1 (Bachelder R.E. et al., 2002). It is also known that tumor associated macrophages (TAM) accumulated in hypoxic areas of tumors and are stimulated to co-operate with tumor cells and promote angiogenesis. It was observed that hypoxia up-regulated

selectively expression of CXCR4 in various cell types including TAM (Mantovani A. et al., 2004). It has been recently demonstrated that CXCR4/SDF-1 axis regulates the trafficking/homing of CXCR4+ hematopoietic stem/progenitor cells (HSC) and could play a role in neovascularization. Evidence indicates that besides HSC, functional CXCR4 is also expressed on stem cells from other tissues (tissue-committed stem cells = TCSCs) so SDF-1 may play a pivotal role in chemottracting CXCR4+ TCSCs necessary for organ/tissue regeneration but these TCSC may also be a cellular origin of cancer development (cancer stem cells theory). A stem cell origin of cancer was demonstrated for human leukemia and recently for several solid tumors such as brain and breast. There are several examples of CXCR4+ tumors that may derive from the normal CXCR4+ tissue/organ-specific stem cells such as leukemias, brain tumors, small cell lung cancer, breast cancer, hepatoblastoma, ovarian and cervical cancers (Kucia M. et al., 2005).

Targeting cancer metastases by interfering with CXCR4 receptor was demonstrated *in vivo* using a monoclonal antibody directed against CXCR4 receptor (Muller A. et al., 2001). Briefly, it was shown that a monoclonal antibody directed against CXCR4 receptor (Mab 173 R&D Systems) decreased significantly the number of lymph node metastases in an orthotopic breast cancer model (MDA-MB231) in SCID mice. Another study (Phillips R.J et al., 2003) also showed the critical role of SDF-1/CXCR4 axis in metastases in an orthotopic lung carcinoma model (A549) using polyclonal antibodies against SDF-1 but in this study there was no effect neither on tumor growth nor on angiogenesis. Several other studies described also the inhibition of either metastasis *in vivo* using siRNAs duplexes of CXCR4 (Liang Z. et al., 2005) biostable CXCR4 peptide antagonists (Tamamura H. et al., 2003) or tumor growth *in vivo* using small molecule antagonist of CXCR4 like AMD 3100 (Rubin J.B. et al., 2003; De Falco V. et al., 2007) or Mab (patent WO2004/059285 A2). Thus, CXCR4 is a validated therapeutic target for cancers.

Chemokine receptor 2 (CXCR2), another chemokine receptor is also described as an interesting target in oncology. Indeed, CXCR2 transmits an autocrine cell growth signal in several tumor cell types and can also affect tumor growth indirectly by promoting angiogenesis (Tanaka T. et al. 2005).

CXCR2 chemokine receptor encompasses 360 amino acids. It is expressed mainly in endothelial cells and specialy during neovascularization. Several chemokines bind CXCR2 receptor: CXCL5, -6, -7, IL-8, GRO-α, -β and γ which belong to ERL+ pro-angiogenic chemokines. The CXCR2 receptor share sequence homologies with CXCR4 receptor: 37% sequence identity and 48% sequence homology. The CXCR2/ligands axis is involved in several tumor growth mechanisms such as metastasis (Singh RK. et al., 1994) cell proliferation (Owen J.D. et al., 1997) and in ERL+ chemokines-mediated angiogenesis (Strieter R.M. et al., 2004; Romagnani et al., 2004). Finally, tumor-associated macrophages and neutrophils are key elements of inflammatory-induced tumor growth and chemokines such as CXCL5, IL-8 and GRO-α initiate neutrophils recruitment.

Dimerization has emerged as a common mechanism for regulating the function of G-protein-coupled receptors, among these are chemokine receptors (Wang J. and Norcross M., 2008). Homo- and heterodimerization in response to chemokine binding has been shown to be required for the initiation and the alteration of signaling by a number of chemokine receptors. Growing evidence supports the concept that receptor dimers or oligomers are probably the basic functional unit of chemokine receptors. Chemokine receptor dimers are found in the absence of ligands and chemokines induce conformational changes of receptor dimers. CXCR4 is known to form homodimers but also heterodimers, for examples with the δ-opioid receptor (DOR) (Hereld D., 2008) or CCR2 (Percherancier Y. et al., 2005). In the latter example, peptides derived from the transmembrane domains of CXCR4 inhibited activation by blocking the ligand-induced conformational transitions of the dimer (Percherancier Y. et al., 2005). Another study showed that CXCR4-TM4 peptide, a synthetic peptide of the transmembrane region of CXCR4, decreases energy transfer between protomers of CXCR4 homodimers and inhibits SDF-1-induced migration and actin polymerization in malignant cells (Wang J. et al., 2006). More recently, it was also described that CXCR7 formed functional heterodimers with CXCR4 and enhanced SDF-1-induced signaling (Sierro F. et al., 2007). Other examples of constitutive heterodimers include studies showing CXCR1 and CXCR2 interact as well as forming respective homodimers. No interactions were noted for either of them with another GPCR (alpha(1A)-adrenoreceptor), indicating the specificity of CXCR1 and CXCR2 interaction (Wilson S. et al., 2005).

As previously mentioned, CXCR4 and CXCR2 receptors are interesting tumor targets. Interfering with those receptors should inhibit tumor growth and metastases in a very efficient way, by decreasing tumor cell proliferation, angiogenesis, tumor cell migration and invasion, neutrophils and macrophages recruitment by tumors and by inhibiting CXCR4 cancer stem cells.

One of the inventive aspects of the present invention is to generate a humanized monoclonal antibody inducing CXCR4 dimers conformational changes. The invention encompasses the CXCR4 Mab hz515H7 (or fragments thereof) able to bind and to induce conformational changes of both CXCR4 homodimers and CXCR4/CXCR2 heterodimers, and having strong anti-tumor activities. Hz515H7 induces conformational changes on CXCR4 homodimers but also on CXCR4/CXCR2 heterodimers. This new property should be of interest for cancer therapy application given the important roles of these two chemokine receptors in cancer.

Targeting both homo- and hetero-dimers of receptors has already been found to increase Mab therapeutic effect. Indeed, it has been demonstrated for example, that a Mab (h7C10) targeting both IGF-1R and insulin/IGF-1 hybrid receptors was more potent to inhibit tumor growth *in vivo* than a Mab targeting solely IGF-1R (Pandini G., 2007).

Moreover the anti-CXCR4 Mab hz515H7 is a silent antagonists for CXCR4, it does not change basal signal in *in vitro* assays but inhibits signaling induced by SDF-1 in different assays (GTPγS binding, Ca^{2+} release) and is also able to inhibit SDF-1 induced tumor cells migration *in vitro*.

Molecules acting as either partial agonists or inverse agonists exhibit intrinsic activity in the absence of ligands. These types of molecules stabilize, respectively a high-affinity or a low-affinity GPCR state, even in the absence of ligand, thereby activating or inhibiting downstream signaling cascades (Galandin et al., 2007; Kenakin, 2004).

In case of the hz515H7 Mab, it behaves as a silent antagonist, without any intrinsic activity at CXCR4 receptor in the absence of SDF-1. This pharmacological feature is likely to be associated with less adverse side-effects as compared to partial or inverse agonists, as already observed for opioid receptor ligands (Bosier and Hermans, 2007). Indeed, the functional activity of hz515H7 Mab is totally dependent on the

presence of SDF-1 and no modulation of CXCR4 receptor activity will be observed in tissues and organs where SDF-1 ligand is not expressed, secreted or provided by the blood flow. Thus, hz515H7 Mab is likely to be less toxic as compared to other CXCR4 receptor ligands with positive or negative efficacy. In addition, silent antagonists are the minority species in the pharmacological space (Wurch et al., 1999, Kenakin, 2004).

In one aspect of the present disclosure, there is provided a humanized antibody capable of binding specifically to CXCR4, or a derived

compound or functional fragment of same, characterized in that the said humanized antibody, or derived compound of functional fragment of same, comprises heavy and light chains, said heavy chain having CDRs consisting of CDR-H1, CDR-H2 and CDR-H3, and the said light chain having CDRs consisting of CDR-L1, CDR-L2 and CDR-L3, wherein said CDR-H1, CDR-H2 and CDR-H3 comprise respectively the sequences SEQ ID Nos. 4, 5 and 6, and said CDR-L1, CDR-L2 and CDR-L3 comprise respectively the sequences SEQ ID Nos. 7, 8 and 9.

In another aspect, there is provided an isolated nucleic acid molecule characterized in that it is selected among the following nucleic acids:

a) a nucleic acid, DNA or RNA, coding for a humanized antibody, or for a derived compound or functional fragment of same, as defined herein;

b) a nucleic acid complementary to a nucleic acid as defined in a);

c) a nucleic acid of at least 18 nucleotides capable of hybridizing under highly stringent conditions with at least one of the 3 CDRs of a heavy chain comprising the nucleic acid sequences SEQ ID Nos. 38 to 41, 49 to 52, 93 or 95; and

d) a nucleic acid of at least 18 nucleotides capable of hybridizing under highly stringent conditions with at least one of the 3 CDRs of a light chain comprising the nucleic acid sequences SEQ ID Nos. 42 to 48, 53 to 59, 94 or 96.

In another aspect, there is provided a vector composed of a nucleic acid as defined herein.

In another aspect, there is provided a host cell comprising a vector as defined herein.

In another aspect, there is provided a transgenic animal, except for man, comprising a cell transformed by a vector as defined herein.

In another aspect, there is provided a method for producing a humanized antibody, or a derived compound or functional fragment of same, characterized in that said method comprises the following steps: the culture in a medium of and the suitable culture conditions for a host cell as defined herein; and the recovery of said antibody, or one of its functional fragments, thus produced from the culture medium or from said cultured cells.

In another aspect, there is provided a humanized antibody, or a derived compound or functional fragment of same, as defined herein, for use as a drug.

In another aspect, there is provided a composition comprising as an active ingredient a compound consisting of a humanized antibody, or a derived compound or functional fragment of same, as defined herein.

In another aspect, there is provided a composition as defined herein, for use as a drug.

In another aspect, there is provided a humanized antibody, or a derived compound or functional fragment of same, as defined herein, and/or of a composition as defined herein, for the prevention or treatment of cancer.

In another aspect, there is provided a process of detecting in vitro the presence and/or the location of a CXCR4 expressing tumor in a subject, wherein said process comprises the steps of: (a) contacting a sample form the subject with a humanized antibody, or a derived compound or functional fragment of same, as defined herein; and (b) detecting the binding of said antibody with the sample.

In another aspect, there is provided a kit comprising at least a humanized antibody, or a derived compound or functional fragment of same, as defined herein, said antibody being preferably labeled.

Surprisingly, for the first time, inventors have managed to generate a humanized antibody capable of binding to CXCR4 but also capable of inducing conformational changes of the CXCR4 homodimers and/or heterodimers. More particularly, the humanized antibody of the invention is capable of inducing conformational changes of the CXCR4 homodimers but also of the CXCR4/CXCR2 heterodimers.

In the following specification, the plural expression "CXCR4 dimers" must be understood as encompassing the CXCR4 homodimers and also the CXCR4/CXCR2 heterodimers.

It must be mentioned at this stage that such humanized antibodies have never been described in the prior art. Moreover, it must be mentioned that the existence of CXCR4/CXCR2 heterodimers was never described.

A part of the invention is the discovery of the existence of a heterodimer formed by CXCR4 and CXCR2.

So, in a particular aspect, the present invention discloses an isolated complex comprising or consisting of the CXCR4/CXCR2 heterodimer.

CXCR4 compound part of said CXCR4/CXCR2 heterodimer complex is one of the two human CXCR4 isoforms selected from the group consisting of:

- the chemokine (C-X-C motif) receptor 4 isoform b [Homo sapiens] having the sequence as depicted under the Genbank accession number NP_003458 (SEQ ID No. 1);
- the chemokine (C-X-C motif) receptor 4 isoform a [Homo sapiens] having the sequence as depicted under the Genbank accession number NP_001008540 SEQ ID No. 2);
- an alternate transcriptional splice variant or a natural variant thereof having at least 95 % identity with one of these b or a isoforms having the SEQ ID No. 1 or 2; and

- a fragment thereof capable of being specifically recognizing by its natural ligand stromal cell-derived factor-1 (SDF-1) and having preferably at least 100, 150 and 200 amino acid length.

CXCR2 compound part of said CXCR4/CXCR2 heterodimer complex is selected from the group consisting of:

- the interleukin 8 receptor beta [Homo sapiens] having the sequence as depicted under the Genbank accession number NP_001548 (SEQ ID No. 3);
- an alternate transcriptional splice variant or a natural variant thereof having at least 95 % identity with this interleukin 8 receptor beta having the SEQ ID No. 3; and
- a fragment thereof capable of being specifically recognizing by IL-8 and having preferably at least 100, 150 and 200 amino acid length.

In this particular aspect, the present invention also discloses an isolated RNA or DNA encoding for a polypeptide comprising said CXCR4/CXCR2 heterodimer complex.

This invention further discloses a nucleic construct, preferably an expression vector, such as a plasmid, encoding said CXCR4/CXCR2 heterodimer complex.

The invention further comprises a composition comprising at least one nucleic construct, preferably an expression vector, such as a plasmid, encoding the part CXCR4 of said CXCR4/CXCR2 heterodimer complex, and a second construct, preferably an expression vector, such as a plasmid, encoding the part CXCR2 of said CXCR4/CXCR2 heterodimer complex.

In this aspect, the invention further discloses a method for the preparation of a recombinant host cell which expresses said CXCR4/CXCR2 heterodimer complex, wherein this method comprises a step of transforming said host cell:

a) with a nucleic construct, preferably an expression vector, such as a plasmid, encoding said CXCR4/CXCR2 heterodimer complex; or

b) with at least one nucleic construct, preferably an expression vector, such as a plasmid, encoding the part CXCR4 of said CXCR4/CXCR2 heterodimer complex, and a second construct, preferably an expression vector, such as a plasmid, encoding the part CXCR2 of said CXCR4/CXCR2 heterodimer complex.

Said host cell is an eukaryotic cell, such as a mammalian cell.

The nucleic construct(s) encoding said CXCR4/CXCR2 heterodimer complex encode also for a first marker which is associated (particularly by covalent coupling) with the CXCR4 sequence, such as the luc marker, and for a second marker which is associated (particularly by covalent coupling) with the CXCR2 sequence, such as the GFP marker (i.e. for BRET analysis).

The invention also discloses a method for selecting a compound having an anti-cancer activity or which can be used for the preparation of a composition for the treatment of cancer, characterized in that said method comprises the step of:

a) contacting a recombinant host cell of the present invention which expresses said CXCR4/CXCR2 heterodimer complex, with the compound to be tested; and

b) determining whether this compound is capable of modulating, preferably inhibiting, the activity of this CXCR4/CXCR2 heterodimer complex in the recombinant host cell.

In a first aspect, a subject of the present invention is a process for the generation and the selection of humanized antibodies according to the invention.

In a first aspect the invention concerns a process for the selection of an anti CXCR4 humanized antibody, or one of its functional fragments or derivatives, capable to inhibit both ligand-dependent and ligand-independent activation of CXCR4, said process comprising the following steps:

i) screening the generated humanized antibodies and selecting antibodies capable to bind specifically to CXCR4 and also to modulate CXCR4 activation;

ii) testing the selected antibodies of step i) and selecting antibodies capable to induce CXCR4 homodimers conformational change, and then

iii) testing the selected antibodies of step ii) and selecting antibodies capable to induce CXCR4/CXCR2 heterodimers conformational change.

By the expression "to modulate", it must be understood an increase or an inhibition. Preferably, the selected antibodies of the invention must inhibit the CXCR4 activation.

As it was explained before, the induction of CXCR4 dimers conformational changes is a capital aspect of the invention as such antibodies will present a real interest for a larger population of patients.

The generation of the antibody can be realized by any method known by the man skilled in the art, such as for example, from recombinant humanized antibodies

designed from the sequenced CDRs of murine antibodies secreted by a fusion of a myeloma cell with spleen cells from immunized mice or other species compatible with the selected myeloma cells [Kohler & Milstein, 1975, Nature, 256:495-497]. The immunized animals could include transgenic mice with human immunoglobulin loci which then directly produce human antibodies. Another possible embodiment could consist in using phage display technologies to screen libraries.

The screening step i) can be realized by any method or process known by the man skilled in the art. As non limitative examples, can be mentioned ELISA, BIAcore, immunohistochemistry, FACS analysis and functional screens. A preferred process consists in a screen by FACS analysis on CXCR4 transfectant and on at least a tumoral cell line to be sure that the produced antibodies will be able to also recognize the native receptor on tumor cells. This process will be described more precisely in the following examples.

By the expression "to modulate CXCR4 activation" it is intended to modulate at least one of the activities depicted in the examples 4, 5, 7 and 11 for the murine antibody, 16, 17 and 19 for the chimeric one and 27, 24 and 28 for the humanized one below:

Preferably to modulate:

- The specific binding at cellular membranes of the ligand SDF-1 on the receptor CXCR4 (see examples 4, 16, 27), particularly by competition on eukaryotic transformed cell membrane, such as CHO-K1 membranes, stably expressing human wild type CXCR4 receptor;
- The specific binding at cellular membranes of the GTPγS on the receptor CXCR4 (see examples 5, 17, 24), particularly on eukaryotic transformed cells membrane, such as NIH-3T3 cells, stably and constitutively expressing wild-type CXCR4 receptor membranes;
- The CXCR4-mediated inhibition of cAMP production (see Example 7); and
- The CXCR4 receptor-mediated mobilization of intracellular calcium stores (see Examples 11, 19, 28).

More preferably, this modulation of at least one of these activities is an inhibition of the activity.

In a preferred embodiment of the steps ii) and iii) of selection of the process of the invention, said steps ii) and iii) consist in evaluating antibodies by BRET analysis on cells expressing CXCR4-RLuc/CXCR4-YFP and CXCR4-Rluc/CXCR2-YFP, respectively, and selecting antibodies capable to inhibit at least 40 %, preferably 45 %, 50 %, 55 % and most preferably 60 % of the BRET signal.

The technology BRET is a technology known as being representative of the protein dimerization [Angers et al., PNAS, 2000, 97:3684-89].

The technology BRET, used in the steps ii) and iii) of the process, is well known by the man skilled in the art and will be detailed in the following examples. More particularly, BRET (Bioluminescence Resonance Energy Transfer) is a non-radiative energy transfer occurring between a bioluminescent donor (Renilla Luciferase (Rluc)) and a fluorescent acceptor, a mutant of GFP (Green Fluorescent Protein) or YFP (Yellow fluorescent protein). In the present case EYFP (Enhanced Yellow Fluorescent Protein) was used. The efficacy of transfer depends on the orientation and the distance between the donor and the acceptor. Then, the energy transfer can occur only if the two molecules are in close proximity (1-10 nm). This property is used to generate protein-protein interaction assays. Indeed, in order to study the interaction between two partners, the first one is genetically fused to the Renilla Luciferase and the second one to the yellow mutant of the GFP. Fusion proteins are generally, but not obligatory, expressed in mammalian cells. In presence of its membrane permeable substrate (coelenterazine), Rluc emits blue light. If the GFP mutant is closer than 10 nm from the Rluc, an energy transfer can occur and an additional yellow signal can be detected. The BRET signal is measured as the ratio between the light emitted by the acceptor and the light emitted by the donor. So the BRET signal will increase as the two fusion proteins are brought into proximity or if a conformational change brings Rluc and GFP mutant closer.

If the BRET analysis consists in a preferred embodiment, any method known by the man skilled in the art can be used to measure CXCR4 dimers conformational changes. Without limitation, the following technologies can be mentioned: FRET (Fluorescence Resonance Energy Transfer), HTRF (Homogenous Time resolved Fluorescence), FLIM (Fluorescence Lifetime Imaging Microscopy) or SW-FCCS single wavelength fluorescence cross-correlation spectroscopy).

Other classical technologies could also be used, such as Co-immunoprecipitation, Alpha screen, Chemical cross-linking, Double-Hybrid, Affinity Chromatography, ELISA or Far western blot.

In a particular aspect of the process according to the invention, step ii) consists in evaluating antibodies by BRET analysis on cells expressing both CXCR4-RLuc/CXCR4-YFP and selecting antibodies capable to inhibit at least 40 %, of the BRET signal.

In another particular aspect of the process according to the invention, step iii) consists in evaluating antibodies by BRET analysis on cells expressing both CXCR4-RLuc/CXCR2-YFP and selecting antibodies capable to inhibit at least 40 %, of the BRET signal.

In a second aspect, a subject of the invention is an isolated humanized antibody, or one of its functional fragments or derivatives, being obtained by said process. Said humanized antibody or one of its said fragments or derivatives, is capable of binding specifically to the human CXCR4 and, if necessary, preferably moreover capable of inhibiting the natural attachment of its ligand, said humanized antibody being also capable to induce CXCR4 dimers conformational changes.

The expressions "functional fragments and derivatives" will be defined in details later in the present specification.

It must be understood here that the invention does not relate to the antibodies in natural form, that is to say they are not in their natural environment but that they have been able to be isolated or obtained by purification from natural sources, or else obtained by genetic recombination, or by chemical synthesis, and that they can then contain unnatural amino acids as will be described further on.

More particularly, according to another aspect of the invention, it is described an antibody, or one of its functional fragments or derivatives, said humanized antibody being characterized in that it comprises at least one complementary determining region CDR, as defined according to IMGT, chosen from CDRs comprising the amino acid sequence SEQ ID Nos. 4 to 9.

According to a second aspect, the invention relates to an isolated humanized antibody, or a derived compound or functional fragment of same, comprising at least one CDR chosen among the CDRs of sequences SEQ ID Nos. 4, 5, 6, 7, 8 or 9 or at

least one CDR, as defined according to IMGT, whose sequence has at least 80%, preferably 85%, 90%, 95% and 98% identity after optimal alignment with sequences SEQ ID No. 4, 5, 6, 7, 8 or 9.

A "functional fragment" of an antibody means in particular an antibody fragment with the same specificity to CXCR4 as the parental antibody, such as fragments Fv, scFv (sc=single chain), Fab, $F(ab')_2$, Fab', scFv-Fc or diabodies, or any fragment whose half-life has been increased. Such functional fragments will be described in detail later in the present description.

A "derived compound" or "derivative" of an antibody means in particular a binding protein composed of a peptide scaffold and at least one of the CDRs of the original antibody in order to preserve its ability to recognize CXCR4. Such derived compounds, well-known to a person skilled in the art, will be described in more detail later in the present description. In another embodiment of the invention, the derived compound or derivative can comprise at least 2, preferably at least 3, more preferably 4, still more preferably 5 or, most preferably, 6 CDRs of the original antibody.

More preferably, the invention comprises the humanized antibodies, their derived compounds or their functional fragments, according to the present invention, obtained by genetic recombination or chemical synthesis.

According to a preferred embodiment, the humanized antibody according to the invention, or its derived compounds or functional fragments, is characterized in that it consists of a monoclonal antibody.

"Monoclonal antibody" is understood to mean an antibody arising from a nearly homogeneous antibody population. More particularly, the individual antibodies of a population are identical except for a few possible naturally-occurring mutations which can be found in minimal proportions. In other words, a monoclonal antibody consists of a homogeneous antibody arising from the growth of a single cell clone (for example a hybridoma, a eukaryotic host cell transfected with a DNA molecule coding for the homogeneous antibody, a prokaryotic host cell transfected with a DNA molecule coding for the homogeneous antibody, etc.) and is generally characterized by heavy chains of one and only one class and subclass, and light chains of only one type. Monoclonal antibodies are highly specific and are directed against a single antigen. In addition, in contrast with preparations of polyclonal antibodies which typically include various

antibodies directed against various determinants, or epitopes, each monoclonal antibody is directed against a single epitope of the antigen.

It must be understood here that the invention does not relate to humanized antibodies in natural form, i.e., they are not taken from their natural environment but are isolated or obtained by purification from natural sources or obtained by genetic recombination or chemical synthesis and thus they can carry unnatural amino acids as will be described below.

More particularly, according to a preferred embodiment of the invention, the humanized antibody, or its derived compounds or functional fragments, is characterized in that it comprises a heavy chain comprising at least one CDR chosen among the CDRs of amino acid sequences SEQ ID Nos. 4, 5 or 6, or at least one CDR whose sequence has at least 80%, preferably 85%, 90%, 95% and 98% identity after optimal alignment with sequences SEQ ID Nos. 4, 5 or 6; or it comprises a light chain comprising at least one CDR chosen among the CDRs of amino acid sequences SEQ ID No. 7, 8 or 9, or at least one CDR whose sequence has at least 80%, preferably 85%, 90%, 95% and 98% identity after optimal alignment with sequences SEQ ID No. 7, 8 or 9.

In a preferred manner, the humanized antibodies of the invention, or one of their derived compounds or functional fragments, are characterized in that they comprise a heavy chain comprising the following three CDRs, respectively CDR-H1, CDR-H2 and CDR-H3, wherein:

- CDR-H1 comprises the sequence SEQ ID No. 4, or a sequence with at least 80%, preferably 85%, 90%, 95% and 98%, identity after optimal alignment with sequence SEQ ID No. 4;
- CDR-H2 comprises the sequences SEQ ID No. 5, or a sequence with at least 80%, preferably 85%, 90%, 95% and 98%, identity after optimal alignment with sequence SEQ ID No. 5; and
- CDR-H3 comprises the sequences SEQ ID No. 6, or a sequence with at least 80%, preferably 85%, 90%, 95% and 98%, identity after optimal alignment with sequence SEQ ID No. 6.

According to a particular embodiment, antibodies, or one of their derived compounds or functional fragments, are characterized in that they comprise a heavy

chain comprising the CDR-H1 of the sequence SEQ ID No. 4, the CDR-H2 of the sequence SEQ ID No. 5 and the CDR-H3 of the sequence SEQ ID No. 6.

Even more preferably, the antibodies of the invention, or one of their derived compounds or functional fragments, are characterized in that they comprise a light chain comprising the following three CDRs, respectively CDR-L1, CDR-L2 and CDR-L3, wherein:

- CDR-L1 comprises the sequence SEQ ID No. 7, or a sequence with at least 80%, preferably 85%, 90%, 95% and 98%, identity after optimal alignment with sequence SEQ ID No. 7;
- CDR-L2 comprises the sequences SEQ ID No. 8, or a sequence with at least 80%, preferably 85%, 90%, 95% and 98%, identity after optimal alignment with sequence SEQ ID No. 8; and
- CDR-L3 comprises the sequence SEQ ID No. 9, or a sequence with at least 80%, preferably 85%, 90%, 95% and 98%, identity after optimal alignment with sequence SEQ ID No. 9.

According to a particular embodiment, antibodies, or one of their derived compounds or functional fragments, are characterized in that they comprise a light chain comprising the CDR-L1 of the sequence SEQ ID No. 7, the CDR-L2 of the sequence SEQ ID No. 8 and the CDR-L3 of the sequence SEQ ID No. 9.

In the present description, the terms "polypeptides", "polypeptide sequences", "peptides" and "proteins attached to antibody compounds or to their sequences" are interchangeable.

It must be understood here that the invention does not relate to antibodies in natural form, i.e., they are not taken from their natural environment but are isolated or obtained by purification from natural sources or obtained by genetic recombination or chemical synthesis and thus they can carry unnatural amino acids as will be described below.

The IMGT unique numbering has been defined to compare the variable domains whatever the antigen receptor, the chain type, or the species [Lefranc M.-P., Immunology Today 18, 509 (1997) / Lefranc M.-P., The Immunologist, 7, 132-136 (1999) / Lefranc, M.-P., Pommié, C., Ruiz, M., Giudicelli, V., Foulquier, E., Truong, L., Thouvenin-Contet, V. and Lefranc, Dev. Comp. Immunol., 27, 55-77 (2003)]. In the

IMGT unique numbering, the conserved amino acids always have the same position, for instance cystein 23 (1st-CYS), tryptophan 41 (CONSERVED-TRP), hydrophobic amino acid 89, cystein 104 (2nd-CYS), phenylalanine or tryptophan 118 (J-PHE or J-TRP). The IMGT unique numbering provides a standardized delimitation of the framework regions (FR1-IMGT: positions 1 to 26, FR2-IMGT: 39 to 55, FR3-IMGT: 66 to 104 and FR4-IMGT: 118 to 128) and of the complementarity determining regions: CDR1-IMGT: 27 to 38, CDR2-IMGT: 56 to 65 and CDR3-IMGT: 105 to 117. As gaps represent unoccupied positions, the CDR-IMGT lengths (shown between brackets and separated by dots, e.g. [8.8.13]) become crucial information. The IMGT unique numbering is used in 2D graphical representations, designated as IMGT Colliers de Perles [Ruiz, M. and Lefranc, M.-P., Immunogenetics, 53, 857-883 (2002) / Kaas, Q. and Lefranc, M.-P., Current Bioinformatics, 2, 21-30 (2007)], and in 3D structures in IMGT/3Dstructure-DB [Kaas, Q., Ruiz, M. and Lefranc, M.-P., T cell receptor and MHC structural data. Nucl. Acids. Res., 32, D208-D210 (2004)].

Three heavy chain CDRs and 3 light chain CDRs exist. The term CDR or CDRs is used here in order to indicate, according to the case, one of these regions or several, or even the whole, of these regions which contain the majority of the amino acid residues responsible for the binding by affinity of the antibody for the antigen or the epitope which it recognizes.

In the sense of the present invention, the "percentage identity" between two sequences of nucleic acids or amino acids means the percentage of identical nucleotides or amino acid residues between the two sequences to be compared, obtained after optimal alignment, this percentage being purely statistical and the differences between the two sequences being distributed randomly along their length. The comparison of two nucleic acid or amino acid sequences is traditionally carried out by comparing the sequences after having optimally aligned them, said comparison being able to be conducted by segment or by using an "alignment window". Optimal alignment of the sequences for comparison can be carried out, in addition to comparison by hand, by means of the local homology algorithm of Smith and Waterman (1981) [Ad. App. Math. 2:482], by means of the local homology algorithm of Neddleman and Wunsch (1970) [J. Mol. Biol. 48:443], by means of the similarity search method of Pearson and Lipman (1988) [Proc. Natl. Acad. Sci. USA 85:2444] or by means of computer software using

these algorithms (GAP, BESTFIT, FASTA and TFASTA in the Wisconsin Genetics Software Package, Genetics Computer Group, 575 Science Dr., Madison, WI, or by the comparison software BLAST NR or BLAST P).

The percentage identity between two nucleic acid or amino acid sequences is determined by comparing the two optimally-aligned sequences in which the nucleic acid or amino acid sequence to compare can have additions or deletions compared to the reference sequence for optimal alignment between the two sequences. Percentage identity is calculated by determining the number of positions at which the amino acid nucleotide or residue is identical between the two sequences, preferably between the two complete sequences, dividing the number of identical positions by the total number of positions in the alignment window and multiplying the result by 100 to obtain the percentage identity between the two sequences.

For example, the BLAST program, "BLAST 2 sequences" (Tatusova et al., "Blast 2 sequences - a new tool for comparing protein and nucleotide sequences", FEMS Microbiol., 1999, Lett. 174:247–250) available on the site http://www.ncbi.nlm.nih.gov/gorf/bl2.html, can be used with the default parameters (notably for the parameters "open gap penalty": 5, and "extension gap penalty": 2; the selected matrix being for example the "BLOSUM 62" matrix proposed by the program); the percentage identity between the two sequences to compare is calculated directly by the program.

For the amino acid sequence exhibiting at least 80%, preferably 85%, 90%, 95% and 98% identity with a reference amino acid sequence, preferred examples include those containing the reference sequence, certain modifications, notably a deletion, addition or substitution of at least one amino acid, truncation or extension. In the case of substitution of one or more consecutive or non-consecutive amino acids, substitutions are preferred in which the substituted amino acids are replaced by "equivalent" amino acids. Here, the expression "equivalent amino acids" is meant to indicate any amino acids likely to be substituted for one of the structural amino acids without however modifying the biological activities of the corresponding antibodies and of those specific examples defined below.

Equivalent amino acids can be determined either on their structural homology with the amino acids for which they are substituted or on the results of comparative tests of biological activity between the various antibodies likely to be generated.

As a non-limiting example, table 1 below summarizes the possible substitutions likely to be carried out without resulting in a significant modification of the biological activity of the corresponding modified antibody; inverse substitutions are naturally possible under the same conditions.

Table 1

Original residue	**Substitution(s)**
Ala (A)	Val, Gly, Pro
Arg (R)	Lys, His
Asn (N)	Gln
Asp (D)	Glu
Cys (C)	Ser
Gln (Q)	Asn
Glu (E)	Asp
Gly (G)	Ala
His (H)	Arg
Ile (I)	Leu
Leu (L)	Ile, Val, Met
Lys (K)	Arg
Met (M)	Leu
Phe (F)	Tyr
Pro (P)	Ala
Ser (S)	Thr, Cys
Thr (T)	Ser
Trp (W)	Tyr
Tyr (Y)	Phe, Trp
Val (V)	Leu, Ala

It is known by those skilled in the art that in the current state of the art the greatest variability (length and composition) between the six CDRs is found at the three heavy-chain CDRs and, more particularly, at CDR-H3 of this heavy chain. Consequently, it will be evident that the preferred characteristic CDRs of the antibodies of the invention, or of one of their derived compounds or functional fragments, will be the three CDRs of the heavy chain.

Another embodiment of the invention discloses an antibody, or its derived compounds or functional fragments, comprising:

a heavy chain comprising the following three CDRs:

CDR-H1 of the sequence SEQ ID No. 4 or of a sequence with at least 80%, preferably 85%, 90%, 95% and 98% identity after optimal alignment with sequence SEQ ID No. 4;

CDR-H2 of the sequence SEQ ID No. 5 or of a sequence with at least 80%, preferably 85%, 90%, 95% and 98% identity after optimal alignment with sequence SEQ ID No. 5;

CDR-H3 of the sequence SEQ ID No. 6 or of a sequence with at least 80%, preferably 85%, 90%, 95% and 98% identity after optimal alignment with sequence SEQ ID No 6;

and a light chain comprising the following three CDRs:

CDR-L1 of the sequence SEQ ID No. 7 or of a sequence with at least 80%, preferably 85%, 90%, 95% and 98% identity after optimal alignment with sequence SEQ ID No. 7;

CDR-L2 of the sequence SEQ ID No. 8 or of a sequence with at least 80%, preferably 85%, 90%, 95% and 98% identity after optimal alignment with sequence SEQ ID No. 8;

CDR-L3 of the sequence SEQ ID No. 9 or of a sequence with at least 80%, preferably 85%, 90%, 95% and 98% identity after optimal alignment with sequence SEQ ID No. 9.

Another aspect of the invention relates to the functional fragments of the humanized antibody described above. As it will be obvious for the man skilled in the art, a functional fragment is necessarily a binding fragment, i.e. a fragment capable of binding to the same target as the parental antibody. A functional fragment, moreover, retains the function of the parental antibody. In particular, a functional fragment of the invention is capable of modulating, the activation of CXCR4. More preferably, a functional fragment according to the invention is capable of inhibiting the activation of CXCR4. In one embodiment, the CXCR4 activation is ligand dependent; in another embodiment, the said CXCR4 activation is ligand independent.

In a preferred embodiment, the functional fragments of the invention retain the function of the parental antibody consisting in modulating, the activity of the CXCR4/CXCR2 heterodimer complex. Preferably, the said functional fragments retain the capacity of inhibiting the activity of the CXCR4/CXCR2 heterodimer complex.

More particularly, the invention targets an antibody, or its derived compounds or functional fragments, characterized in that said functional fragment is selected among

the fragments Fv, Fab, $(Fab')_2$, Fab', scFv, scFv-Fc and diabodies, or any fragment whose half–life has been increased such as PEGylated fragments.

Such functional fragments of the antibody according to the invention consist, for example, of the fragments Fv, scFv (sc=simple chain), Fab, $F(ab')_2$, Fab', scFv-Fc or diabodies, or any fragment whose half-life has been increased by chemical modification, such as the addition of polyalkylene glycol such as polyethylene glycol (PEGylation) (PEGylated fragments are referred to as Fv-PEG, scFv-PEG, Fab-PEG, $F(ab')_2$-PEG and Fab'-PEG), or by incorporation in a liposome, microspheres or PLGA, said fragments possessing at least one of the characteristic CDRs of the humanized antibodies of the invention which is notably capable of exerting in a general manner activity, even partial, of the antibody from which it arises.

Preferably, said functional fragments will comprise or include a partial sequence of the variable heavy or light chain of the antibody from which they are derived, said partial sequence being sufficient to retain the same binding specificity as the antibody from which it arises and sufficient affinity, preferably at least equal to 1/100, more preferably at least 1/10 of that of the antibody from which it arises.

Such a functional fragment will contain at least five amino acids, preferably 6, 7, 8, 10, 15, 25, 50 or 100 consecutive amino acids of the sequence of the antibody from which it arises.

Preferably, these functional fragments will be of the types Fv, scFv, Fab, $F(ab')_2$, F(ab'), scFv-Fc or diabodies, which generally have the same binding specificity as the antibody from which they result. According to the present invention, fragments of the antibody of the invention can be obtained from the antibodies described above by methods such as enzyme digestion, including pepsin or papain, and/or by cleavage of the disulfide bridges by chemical reduction. The antibody fragments can be also obtained by recombinant genetics techniques also known to a person skilled in the art or by peptide synthesis by means, for example, of automatic peptide synthesizers such as those sold by Applied BioSystems, etc.

More particularly, the invention relates to different humanized antibody variants of the murine 515H7 Mab, referred in the present specification as i) HZ515H7, Hz515H7 or hz515H7 Mab and ii) HZ515H7-2, Hz515H7-2 or hz515H7-2 Mab or iii) any combination of a light chain and/or a heavy chain of the said antibody variants..

For more clarity, table 2a below summarizes the various amino acid sequences corresponding to the CDRs of the humanized variants (also referred as forms) hz515H7 and hz515H7-2 of the invention; table 2b summarizes the various amino acid sequences corresponding to the variable domains and the full length sequences of the various variants of the humanized form hz515H7 of the invention; and table 2c summarizes the various amino acid sequences corresponding to the variable domains and the full length sequences of the humanized form hz515H7-2 of the invention.

Table 2a

Antibody Hz515H7	**Heavy chain**	**Light chain**	**SEQ ID NO.**
CDR(s)	CDR-H1	-	4
	CDR-H2	-	5
	CDR-H3	-	6
	-	CDR-L1	7
	-	CDR-L2	8
	-	CDR-L3	9

Table 2b

Antibody Hz515H7	**Heavy chain**	**Light chain**	**SEQ ID NO.**
Variable Domains	VH1	-	10
	VH1 D76N	-	11
	VH1 V48L D76N	-	12
	VH2	-	13
	-	VL1	14
	-	VL1 T59A E61D	15
	-	VL2	16
	-	VL2.1	17
	-	VL2.2	18
	-	VL2.3	19
	-	VL3	20
Complete Sequences (without signal peptide)	VH1	-	21
	VH1 D76N	-	22
	VH1 V48L D76N	-	23
	VH2	-	24
	-	VL1	25
	-	VL1 T59A E61D	26
	-	VL2	27

	-	VL2.1	28
	-	VL2.2	29
	-	VL2.3	30
	-	VL3	31

Table 2c

Antibody Hz515H7-2	**Heavy chain**	**Light chain**	**SEQ ID NO.**
Variable Domains	"consensus"	-	85
	-	"consensus"	86
	VH1	-	87
	-	VL1	88
Complete Sequences (without signal peptide)	"consensus"	-	89
	-	"consensus"	90
	VH1	-	91
	-	VL1	92

As an example, for the avoidance of doubt, the expression "VH1" is similar to the expressions "VH Variant 1", "VH variant 1", "VH Var 1" or "VH var 1). The obtention of "consensus" sequences is described in Example 22.

Yet another specific aspect of the present invention relates to a humanized antibody, or its derived compounds or functional fragments, characterized in that the constant regions of the light-chain and the heavy-chain derived from human antibody are, respectively, the lambda or kappa region and the gamma-1, gamma-2 or gamma-4 region.

The invention describes the murine hybridoma secreting a monoclonal antibody filed with the French collection for microorganism cultures (CNCM, Institut Pasteur, Paris, France) on June 25, 2008, under number I-4019. Said hybridoma was obtained by the fusion of Balb/C immunized mice splenocytes and cells of the myeloma Sp 2/O-Ag 14 lines.

The murine monoclonal antibody, here referred to as 515H7 is secreted by the hybridoma filed with the CNCM on June 25, 2008, under number I-4019.

The invention also describes chimeric antibodies.

A chimeric antibody is one containing a natural variable region (light chain and heavy chain) derived from an antibody of a given species in combination with constant

regions of the light chain and the heavy chain of an antibody of a species heterologous to said given species.

These antibodies, or chimeric fragments of same, can be prepared by using the techniques of recombinant genetics. For example, the chimeric antibody could be produced by cloning recombinant DNA containing a promoter and a sequence coding for the variable region of a nonhuman monoclonal antibody of the invention, notably murine, and a sequence coding for the human antibody constant region. A chimeric antibody according to the invention coded by one such recombinant gene could be, for example, a mouse-human chimera, the specificity of this antibody being determined by the variable region derived from the murine DNA and its isotype determined by the constant region derived from human DNA. Refer to Verhoeyn *et al.* (BioEssays, 8:74, 1988) for methods for preparing chimeric antibodies.

In another embodiment, the invention relates to a chimeric antibody heavy chain (referred as c515H7 VH) comprising a variable region of sequence selected SEQ ID No. 83.

In another embodiment, the invention relates to a chimeric antibody light chain (referred as c515H7 VL) comprising a variable region of sequence SEQ ID No. 84.

In a particular preferred embodiment, the chimeric antibody, or a derived compound or functional fragment of same, of the invention comprises a heavy chain sequence comprising the amino acid sequence SEQ ID No. 83, and a light chain sequence comprising the amino acid sequence SEQ ID No.84.

A "humanized antibody", as used herein, refers to an antibody that comprises at least one heavy chain or one light chain, said heavy or light chain containing CDR regions derived from an antibody of nonhuman origin, the other parts of the antibody molecule being of human origin (for example, the said other parts may be derived from one (or several) human antibodies). By the expression "humanized antibody", the present invention thus comprises antibodies with only one humanized chain, the second being a chimeric or murine chain. Preferably, a "humanized antibody" of the invention comprises two humanized chains, i.e. both the heavy chain and the light chain are humanized.

The humanized antibodies of the invention or fragments of same can be prepared by techniques known to a person skilled in the art (such as, for example, those described

in the documents Singer *et al.*, J. Immun., 150:2844-2857, 1992; Mountain *et al.*, Biotechnol. Genet. Eng. Rev., 10:1-142, 1992; and Bebbington *et al.*, Bio/Technology, 10:169-175, 1992). Such humanized antibodies are preferred for their use in methods involving *in vitro* diagnoses or preventive and/or therapeutic treatment *in vivo*. Other humanization techniques, also known to a person skilled in the art, such as, for example, the "CDR grafting" technique described by PDL in patents EP 0 451 216, EP 0 682 040, EP 0 939 127, EP 0 566 647 or US 5,530,101, US 6,180,370, US 5,585,089 and US 5,693,761. US patents 5,639,641 or 6,054,297, 5,886,152 and 5,877,293 can also be cited.

The invention relates to the humanized antibodies arising from the murine antibody 515H7 described above.

In a preferred manner, constant regions of the light-chain and the heavy-chain derived from human antibody are, respectively, the lambda or kappa and the gamma-1, gamma-2 or gamma-4 region.

More particularly, the invention relates to a humanized antibody heavy chain comprising i) a framework region homologous to corresponding framework region of a human antibody heavy chain, and ii) CDRs homologous to corresponding CDRs of an antibody derived from a different mammalian species, wherein said CDRs consist of CDR-H1, CDR-H2 and CDR-H3 comprising respectively the sequences SEQ ID Nos. 4, 5 and 6.

In other words, the invention relates to a humanized antibody heavy chain having CDRs consisting of CDR-H1, CDR-H2 and CDR-H3, said CDR-H1, CDR-H2 and CDR-H3 comprising respectively the sequences SEQ ID Nos. 4, 5 and 6. It will be obvious, for the man skilled in the art, that different germlines can be selected for the humanization of the antibody 515H7, resulting then in different forms of humanized 515H7. More particularly, in a preferred non limitative embodiment, different germlines can be used for the sequence coding the v genes whereas the same germlines will be conserved for the j-genes.

For the present invention, germlines which could be used are selected on the bases of two complementary criteria:

- the length in amino acids for each CDRs must be identical between the murine CDR and the equivalent in the Germline ; and

- the germline sequence in amino acids must have at least 70 % of identity with the parental murine sequence.

For the avoidance of doubt, it is reminded here that the present invention encompasses two preferred non limitative humanized forms (also referred as versions) of the same antibody 515H7. The first one, referred as Hz515H7, consists of a humanized antibody obtained with the germlines IGHV3-49*04 (SEQ ID No. 77) and IGHJ4*01 (SEQ ID No. 81) for the heavy chain and IGKV4-1*01 (SEQ ID No. 78) and IGKJ1*01 (SEQ ID No. 82) for the light chain. The second one, referred as Hz515H7-2, consists of a humanized antibody obtained with the germlines IGHV3-73*01 (SEQ ID No. 79) and IGHJ4*01 (SEQ ID No. 81) for the heavy chain and IGKV2D-40*01 (SEQ ID No. 80) and IGKJ1*01 (SEQ ID No. 82) for the light chain.

In another embodiment, the invention relates to a humanized antibody heavy chain comprising a variable region of sequence selected from the group consisting of SEQ ID Nos. 10, 11, 12, 13, 85 or 87.

In another embodiment, the invention relates to the humanized antibody H515H7 heavy chain comprising a variable region of sequence selected from the group consisting of SEQ ID Nos. 10, 11, 12 or 13.

In another embodiment, the invention relates to the humanized antibody H515H7-2 heavy chain comprising a variable region of sequence SEQ ID No. 85.

In another embodiment, the invention relates to the humanized antibody H515H7-2 heavy chain comprising a variable region of sequence SEQ ID No. 87.

In still another embodiment, the invention also relates to the humanized antibody H515H7-2 heavy chain variable region of sequence SEQ ID No. 87 which comprises one or more amino acid substitution(s) selected from the group consisting of H35S, V48L, R50F, A61D, D76N and A81L.

In still another embodiment, the invention relates to a humanized antibody heavy chain comprising the complete sequence selected from the group consisting of SEQ ID Nos. 21, 22, 23, 24, 89 or 91.

In still another embodiment, the invention relates to a humanized antibody heavy chain comprising the complete sequence selected from the group consisting of SEQ ID Nos. 21, 22, 23 or 24.

In another embodiment, the invention relates to the humanized antibody H515H7-2 heavy chain comprising the complete sequence SEQ ID No. 89.

In another embodiment, the invention relates to the humanized antibody H515H7-2 heavy chain comprising the complete sequence SEQ ID No. 91.

In still another embodiment, the invention also relates to the humanized antibody H515H7-2 heavy chain of sequence SEQ ID No. 91 which comprises one or more amino acid substitution(s) selected from the group consisting of H35S, V48L, R50F, A61D, D76N and A81L.

More particularly, the invention relates to a humanized antibody light chain comprising i) a framework region homologous to corresponding framework region of a human antibody light chain, and ii) CDRs homologous to corresponding CDRs of an antibody derived from a different mammalian species, wherein said CDRs consist of CDR-L1, CDR-L2 and CDR-L3 comprising respectively the sequences SEQ ID Nos. 7, 8 and 9.

In other words, the invention relates to a humanized antibody light chain having CDRs consisting of CDR-L1, CDR-L2 and CDR-L3, said CDR-L1, CDR-L2 and CDR-L3 comprising respectively the sequences SEQ ID Nos. 7, 8 and 9.

In another embodiment, the invention relates to a humanized antibody light chain comprising a variable region of sequence selected from the group consisting of SEQ ID Nos. 14, 15, 16, 17, 18, 19, 20, 86 or 88.

In another embodiment, the invention relates to the humanized antibody H515H7 light chain comprising a variable region of sequence selected from the group consisting of SEQ ID Nos. 14, 15, 16, 17, 18, 19 or 20.

In another embodiment, the invention relates to the humanized antibody H515H7-2 light chain comprising a variable region of sequence SEQ ID No. 86.

In another embodiment, the invention relates to the humanized antibody H515H7-2 light chain comprising a variable region of sequence SEQ ID No. 88.

In still another embodiment, the invention also relates to the humanized antibody H515H7-2 light chain variable region of sequence SEQ ID No. 88 which comprises one or more amino acid substitution(s) selected from the group consisting of L9S, I21M, D40A, L43Q, Y59A, A61D, D66A, S69T, G74E, D76Y and/orV89L.

In still another embodiment, the invention relates to a humanized antibody light chain comprising the complete sequence selected from the group consisting of SEQ ID Nos. 25, 26, 27, 28, 29, 30, 31, 90 or 92.

In another embodiment, the invention relates to the humanized antibody H515H7 light chain comprising the complete sequence selected from the group consisting of SEQ ID Nos. 25, 26, 27, 28, 29, 30 or 31.

In another embodiment, the invention relates to the humanized antibody H515H7-2 light chain comprising the complete sequence SEQ ID No. 90.

In another embodiment, the invention relates to the humanized antibody H515H7-2 light chain comprising the complete sequence SEQ ID No. 92.

In still another embodiment, the invention also relates to the humanized antibody H515H7-2 light chain of sequence SEQ ID No. 92 which comprises one or more amino acid substitution(s) selected from the group consisting of L9S, I21M, D40A, L43Q, Y59A, A61D, D66A, S69T, G74E, D76Y and/orV89L.

More particularly, the invention relates to a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises heavy and light chains each having i) framework regions homologous to corresponding framework regions of a human antibody, and ii) CDRs homologous to corresponding CDRs of an antibody derived from a different mammalian species, wherein said CDRs consist of CDR-H1, CDR-H2 and CDR-H3 of the heavy chain comprising respectively the sequences SEQ ID Nos. 4, 5 and 6, and CDR-L1, CDR-L2 and CDR-L3 of the light chain comprising respectively the sequences SEQ ID Nos. 7, 8 and 9.

In other words, the invention relates to a humanized antibody, or a derived compound or functional fragment of same, characterized in that the said humanized antibody comprises heavy and light chains, said heavy chain having CDRs consisting of CDR-H1, CDR-H2 and CDR-H3, and the said light chain having CDRs consisting of CDR-L1, CDR-L2 and CDR-L3, wherein said CDR-H1, CDR-H2 and CDR-H3

comprise respectively the sequences SEQ ID Nos. 4, 5 and 6, and said CDR-L1, CDR-L2 and CDR-L3 comprise respectively the sequences SEQ ID Nos. 7, 8 and 9.

In another embodiment, the invention relates to a humanized antibody, or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence selected from the group consisting of SEQ ID Nos. 10, 11, 12, 13, 83, 85 or 87 and a light chain variable region of sequence selected from the group consisting of SEQ ID Nos. 14, 15, 16, 17, 18, 19, 20, 84, 86 or 88.

In another embodiment, the invention relates to the humanized antibody H515H7 comprising a heavy chain variable region selected from the group consisting of SEQ ID Nos. 10, 11, 12 or 13 and a light chain variable region of sequence selected from the group consisting of SEQ ID Nos. 14, 15, 16, 17, 18, 19 or 20.

In another embodiment, the invention relates to the humanized antibody H515H7-2 comprising a heavy chain variable region of sequence SEQ ID No. 85 and a light variable region of sequence SEQ ID No. 86.

In another embodiment, the invention relates to the humanized antibody H515H7-2 comprising a heavy chain variable region of sequence SEQ ID No. 87 and a light variable region of sequence SEQ ID No. 88.

In another embodiment, the invention relates to the humanized antibody H515H7-2 comprising a heavy chain variable region of sequence SEQ ID No. 85 and a light variable region of sequence SEQ ID No. 88.

In another embodiment, the invention relates to the humanized antibody H515H7-2 comprising a heavy chain variable region of sequence SEQ ID No. 87 and a light variable region of sequence SEQ ID No. 86.

In still another embodiment, the invention also relates to the humanized antibody H515H7-2 comprising a heavy chain variable region of sequence SEQ ID No. 87 which comprises one or more amino acid substitution(s) selected from the group consisting of H35S, V48L, R50F, A61D, D76N and A81L and light chain variable region of sequence SEQ ID No. 88 which comprises one or more amino acid substitution(s) selected from the group consisting of D40A, L43Q, Y59A, A61D, S69T, G74E and D76Y.

In still another embodiment, the invention relates to a humanized antibody comprising a humanized heavy chain, combined with a chimeric light chain.

In still another embodiment, the invention relates to a humanized antibody comprising a chimeric heavy chain, combined with a humanized light chain.

More particularly, the invention describes a humanized antibody, or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 83 and a light chain variable region of sequence selected from the group consisting of SEQ ID Nos. 14, 15, 16, 17, 18, 19, 20, 86 or 88.

In a preferred embodiment, the invention relates to the humanized antibody c515H7 VH / Hz515H7 VL1 or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 83, and a light chain variable region of sequence SEQ ID No. 14.

In a preferred embodiment, the invention relates to the humanized antibody c515H7 VH / Hz515H7 VL1 T59A E61D or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 83, and a light chain variable region of sequence SEQ ID No. 15.

In a preferred embodiment, the invention relates to the humanized antibody c515H7 VH / Hz515H7 VL2 or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 83, and a light chain variable region of sequence SEQ ID No. 16.

In a preferred embodiment, the invention relates to the humanized antibody c515H7 VH / Hz515H7 VL2.1 or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 83, and a light chain variable region of sequence SEQ ID No. 17.

In a preferred embodiment, the invention relates to the humanized antibody c515H7 VH / Hz515H7 VL2.2 or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 83, and a light chain variable region of sequence SEQ ID No. 18.

In a preferred embodiment, the invention relates to the humanized antibody c515H7 VH / Hz515H7 VL2.3 or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 83, and a light chain variable region of sequence SEQ ID No. 19.

In a preferred embodiment, the invention relates to the humanized antibody c515H7 VH / Hz515H7 VL3 or a derived compound or functional fragment of same,

comprising a heavy chain variable region of sequence SEQ ID No. 83, and a light chain variable region of sequence SEQ ID No. 20.

In a preferred embodiment, the invention relates to a humanized antibody or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 83, and a light chain variable region of sequence SEQ ID No. 86.

In a preferred embodiment, the invention relates to the humanized antibody c515H7 VH / Hz515H7-2 VL1 or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 83, and a light chain variable region of sequence SEQ ID No. 88.

In another embodiment, the invention describes a humanized antibody, or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence selected from the group consisting of SEQ ID Nos. 10, 11, 12, 13, 85 or 87 and a light chain variable region of sequence SEQ ID No. 84.

In a preferred embodiment, the invention relates to the humanized antibody Hz515H7 VH1 / c515H7 VL or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 10, and a light chain variable region of sequence SEQ ID No. 84.

In a preferred embodiment, the invention relates to the humanized antibody Hz515H7 VH1 D76N / c515H7 VL or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 11, and a light chain variable region of sequence SEQ ID No. 84.

In a preferred embodiment, the invention relates to the humanized antibody Hz515H7 VH1 V48L D76N / c515H7 VL or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 12, and a light chain variable region of sequence SEQ ID No. 84.

In a preferred embodiment, the invention relates to the humanized antibody Hz515H7 VH2 / c515H7 VL or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 13, and a light chain variable region of sequence SEQ ID No. 84.

In a preferred embodiment, the invention relates to a humanized antibody or a derived compound or functional fragment of same, comprising a heavy chain variable

region of sequence SEQ ID No. 85, and a light chain variable region of sequence SEQ ID No. 84.

In a preferred embodiment, the invention relates to the humanized antibody Hz515H7-2 VH1 / c515H7 VL or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 87, and a light chain variable region of sequence SEQ ID No. 84.

In still another embodiment, the invention relates to a humanized antibody, or a derived compound or functional fragment of same, comprising a heavy chain of sequence selected from the group consisting of SEQ ID Nos. 21, 22, 23, 24, 89 or 91 and a light chain of sequence selected from the group consisting of SEQ ID Nos. 25, 26, 27, 28, 29, 30, 31, 90 or 92.

In another embodiment, the invention relates to the humanized antibody H515H7 comprising a heavy chain of sequence selected from the group consisting of SEQ ID Nos. 21, 22, 23 or 24 and a light chain of sequence selected from the group consisting of SEQ ID Nos. 25, 26, 27, 28, 29, 30 or 31.

In another embodiment, the invention relates to the humanized antibody H515H7-2 comprising a heavy chain of sequence SEQ ID No. 89 and a light chain of sequence SEQ ID No. 90.

In another embodiment, the invention relates to the humanized antibody H515H7-2 comprising a heavy chain of sequence SEQ ID No. 91 and a light chain of sequence SEQ ID No. 92.

In still another embodiment, the invention also relates to the humanized antibody H515H7-2 comprising a heavy chain of sequence SEQ ID No. 91 which comprises one or more amino acid substitution(s) selected from the group consisting of H35S, V48L, R50F, A61D, D76N and A81L and light chain of sequence SEQ ID No. 92 which comprises one or more amino acid substitution(s) selected from the group consisting of D40A, L43Q, Y59A, A61D, S69T, G74E and D76Y.

In a preferred embodiment, the invention relates to the humanized antibody Hz515H7 VH1 D76N VL2, or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 11, and a light chain variable region of sequence SEQ ID No. 16.

In another preferred embodiment, the invention relates to the humanized antibody Hz515H7 VH1 D76N VL2, or a derived compound or functional fragment of same, comprising a heavy chain of sequence SEQ ID No. 22, and a light chain of sequence SEQ ID No. 27.

In another preferred embodiment, the invention relates to the humanized antibody Hz515H7 VH1 D76N VL2.1, or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 11, and a light chain variable region of sequence SEQ ID No. 17.

In another preferred embodiment, the invention relates to the humanized antibody Hz515H7 VH1 D76N VL2.1, or a derived compound or functional fragment of same, comprising a heavy chain of sequence SEQ ID No. 22, and a light chain of sequence SEQ ID No. 28.

In another preferred embodiment, the invention relates to the humanized antibody Hz515H7 VH1 D76N VL2.2, or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 11, and a light chain variable region of sequence SEQ ID No. 18.

In another preferred embodiment, the invention relates to the humanized antibody Hz515H7 VH1 D76N VL2.2, or a derived compound or functional fragment of same, comprising a heavy chain of sequence SEQ ID No. 22, and a light chain of sequence SEQ ID No. 29.

In another preferred embodiment, the invention relates to the humanized antibody Hz515H7 VH1 D76N VL2.3, or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 11, and a light chain variable region of sequence SEQ ID No. 19.

In another preferred embodiment, the invention relates to the humanized antibody Hz515H7 VH1 D76N VL2.3, or a derived compound or functional fragment of same, comprising a heavy chain of sequence SEQ ID No. 22, and a light chain of sequence SEQ ID No. 30.

In another preferred embodiment, the invention relates to the humanized antibody Hz515H7 VH1 V48L D76N VL1, or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 12, and a light chain variable region of sequence SEQ ID No. 14.

In another preferred embodiment, the invention relates to the humanized antibody Hz515H7 VH1 V48L D76N VL1, or a derived compound or functional fragment of same, comprising a heavy chain of sequence SEQ ID No. 23, and a light chain of sequence SEQ ID No. 25.

In another preferred embodiment, the invention relates to the humanized antibody Hz515H7 VH1 V48L D76N VL1 T59A E61D, or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 12, and a light chain variable region of sequence SEQ ID No. 15.

In another preferred embodiment, the invention relates to the humanized antibody Hz515H7 VH1 V48L D76N VL1 T59A E61D, or a derived compound or functional fragment of same, comprising a heavy chain of sequence SEQ ID No. 23, and a light chain of sequence SEQ ID No. 26.

In another preferred embodiment, the invention relates to the humanized antibody Hz515H7 VH1 VL1, or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 10, and a light chain variable region of sequence SEQ ID No. 14.

In another preferred embodiment, the invention relates to the humanized antibody Hz515H7 VH1 VL1, or a derived compound or functional fragment of same, comprising a heavy chain of sequence SEQ ID No. 21, and a light chain of sequence SEQ ID No. 25.

In a preferred embodiment, the invention relates to the humanized antibody Hz515H7 VH1 / Hz515H7-2 VL1, or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 10, and a light chain variable region of sequence SEQ ID No. 88.

In a preferred embodiment, the invention relates to the humanized antibody Hz515H7 VH1 D76N / Hz515H7-2 VL1, or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 11, and a light chain variable region of sequence SEQ ID No. 88.

In another preferred embodiment, the invention relates to the humanized antibody Hz515H7 VH1 V48L D76N / Hz515H7-2 VL1, or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 12, and a light chain variable region of sequence SEQ ID No. 88.

In another preferred embodiment, the invention relates to the humanized antibody Hz515H7 VH2 / Hz515H7-2 VL1, or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 13, and a light chain variable region of sequence SEQ ID No. 88.

In a preferred embodiment, the invention relates to the humanized antibody Hz515H7 VH1 / Hz515H7-2 VL1, or a derived compound or functional fragment of same, comprising a heavy chain of sequence SEQ ID No. 21, and a light chain of sequence SEQ ID No. 92.

In a preferred embodiment, the invention relates to the humanized antibody Hz515H7 VH1 D76N / Hz515H7-2 VL1, or a derived compound or functional fragment of same, comprising a heavy chain of sequence SEQ ID No. 22, and a light chain of sequence SEQ ID No. 92.

In another preferred embodiment, the invention relates to the humanized antibody Hz515H7 VH1 V48L D76N / Hz515H7-2 VL1, or a derived compound or functional fragment of same, comprising a heavy chain of sequence SEQ ID No. 23, and a light chain of sequence SEQ ID No. 92.

In another preferred embodiment, the invention relates to the humanized antibody Hz515H7 VH2 / Hz515H7-2 VL1, or a derived compound or functional fragment of same, comprising a heavy chain of sequence SEQ ID No. 24, and a light chain of sequence SEQ ID No. 92.

In a preferred embodiment, the invention relates to the humanized antibody Hz515H7-2 VH1 / Hz515H7 VL1, or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 87, and a light chain variable region of sequence SEQ ID No. 14.

In a preferred embodiment, the invention relates to the humanized antibody Hz515H7-2 VH1 / Hz515H7 VL1 T59A E61D, or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 87, and a light chain variable region of sequence SEQ ID No. 15.

In a preferred embodiment, the invention relates to the humanized antibody Hz515H7-2 VH1 / Hz515H7 VL2, or a derived compound or functional fragment of

same, comprising a heavy chain variable region of sequence SEQ ID No. 87, and a light chain variable region of sequence SEQ ID No. 16.

In a preferred embodiment, the invention relates to the humanized antibody Hz515H7-2 VH1 / Hz515H7 VL2.1, or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 87, and a light chain variable region of sequence SEQ ID No. 17.

In a preferred embodiment, the invention relates to the humanized antibody Hz515H7-2 VH1 / Hz515H7 VL2.2, or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 87, and a light chain variable region of sequence SEQ ID No. 18.

In a preferred embodiment, the invention relates to the humanized antibody Hz515H7-2 VH1 / Hz515H7 VL2.3, or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 87, and a light chain variable region of sequence SEQ ID No. 19.

In a preferred embodiment, the invention relates to the humanized antibody Hz515H7-2 VH1 / Hz515H7 VL3, or a derived compound or functional fragment of same, comprising a heavy chain variable region of sequence SEQ ID No. 87, and a light chain variable region of sequence SEQ ID No. 20.

In a preferred embodiment, the invention relates to the humanized antibody Hz515H7-2 VH1 / Hz515H7 VL1, or a derived compound or functional fragment of same, comprising a heavy chain of sequence SEQ ID No. 91, and a light chain of sequence SEQ ID No. 25.

In a preferred embodiment, the invention relates to the humanized antibody Hz515H7-2 VH1 / Hz515H7 VL1 T59A E61D, or a derived compound or functional fragment of same, comprising a heavy chain of sequence SEQ ID No. 91, and a light chain of sequence SEQ ID No. 26.

In a preferred embodiment, the invention relates to the humanized antibody Hz515H7-2 VH1 / Hz515H7 VL2, or a derived compound or functional fragment of same, comprising a heavy chain of sequence SEQ ID No. 91, and a light chain of sequence SEQ ID No. 27.

In a preferred embodiment, the invention relates to the humanized antibody Hz515H7-2 VH1 / Hz515H7 VL2.1, or a derived compound or functional fragment of same, comprising a heavy chain of sequence SEQ ID No. 91, and a light chain of sequence SEQ ID No. 28.

In a preferred embodiment, the invention relates to the humanized antibody Hz515H7-2 VH1 / Hz515H7 VL2.2, or a derived compound or functional fragment of same, comprising a heavy chain of sequence SEQ ID No. 91, and a light chain of sequence SEQ ID No. 29.

In a preferred embodiment, the invention relates to the humanized antibody Hz515H7-2 VH1 / Hz515H7 VL2.3, or a derived compound or functional fragment of same, comprising a heavy chain of sequence SEQ ID No. 91, and a light chain of sequence SEQ ID No. 30.

In a preferred embodiment, the invention relates to the humanized antibody Hz515H7-2 VH1 / Hz515H7 VL3, or a derived compound or functional fragment of same, comprising a heavy chain of sequence SEQ ID No. 91, and a light chain of sequence SEQ ID No. 31.

It must be understood that the above exemplified VH / VL combinations are not limitative. The man skilled in the art could of course, without undue burden and without applying inventive skill, rearrange all the VH and VL disclosed in the present specification. The skilled person could thus obtain all the humanized antibodies corresponding to all the combinations of all the VH and the VL disclosed in the present application.

A novel aspect of the present invention relates to an isolated nucleic acid characterized in that it is selected among the following nucleic acids (including any degenerate genetic code):

a) a nucleic acid, DNA or RNA, coding for a humanized antibody heavy chain, or for a derived compound or functional fragment of same, according to the present invention;

b) a nucleic acid, DNA or RNA, coding for a humanized antibody light chain, or for a derived compound or functional fragment of same, according to the present invention;

c) a nucleic acid, DNA or RNA, coding for a humanized antibody, or for a derived compound or functional fragment of same, according to the present invention;

d) a nucleic acid complementary to a nucleic acid as defined in a), b) or c);

e) a nucleic acid of at least 18 nucleotides capable of hybridizing under highly stringent conditions with at least a heavy chain comprising the nucleic acid sequences SEQ ID No. 38 to 41,49 to 52, 93 or 95 preferably with at least one of the 3 CDRs thereof according to the IMGT or to the Kabat CDR numbering;

f) a nucleic acid of at least 18 nucleotides capable of hybridizing under highly stringent conditions with at least a light chain comprising the nucleic acid sequences SEQ ID No. 42 to 48, 53 to 59, 94 or 96 preferably with at least one of the 3 CDRs thereof according to the IMGT or to the Kabat CDR numbering.

The invention also relates to an isolated nucleic acid molecule comprising a nucleic acid sequence encoding a heavy chain variable region of a humanized antibody, said heavy chain variable region nucleotide sequence comprising a CDR-H1 nucleotide sequence of SEQ ID No. 32; a CDR-H2 nucleotide sequence of SEQ ID No. 33; and a CDR-H3 nucleotide sequence of SEQ ID No. 34.

The invention also relates to an isolated nucleic acid molecule comprising a nucleic acid sequence encoding a light chain variable region of a humanized antibody, said light chain variable region nucleotide sequence comprising a CDR-L1 nucleotide sequence of SEQ ID No. 35 or 60; a CDR-L2 nucleotide sequence of SEQ ID No. 36 or 61; and a CDR-L3 nucleotide sequence of SEQ ID No. 37 or 62.

The invention also relates to an isolated nucleic acid molecule comprising a nucleic acid sequence encoding a heavy chain variable region and a light chain variable region of a humanized antibody,

said heavy chain variable region nucleotide sequence comprising a CDR-H1 nucleotide sequence of SEQ ID No. 32; a CDR-H2 nucleotide sequence of SEQ ID No. 33; and a CDR-H3 nucleotide sequence of SEQ ID No. 34;

said light chain variable region nucleotide sequence comprising a CDR-L1 nucleotide sequence of SEQ ID No. 35 or 60; a CDR-L2 nucleotide sequence of SEQ ID No. 36 or 61; and a CDR-L3 nucleotide sequence of SEQ ID No. 37 or 62.

Table 3a below summarizes the optimized nucleotide sequences corresponding to the CDRs of the antibody hz515H7 of the invention; table 3b summarizes the various optimized nucleotide sequences corresponding to the variable domains and the full length sequences of the various variants of the humanized antibody hz515H7 of the invention. Table 3c summarizes the various optimized nucleotide sequences corresponding to the variable domains and the full length sequences the humanized version hz515H7-2 of the invention.

Table 3a

Antibody Hz515H7	**Heavy chain**	**Light chain**	**SEQ ID NO.**
optimized CDR(s)	CDR-H1	-	32
	CDR-H2	-	33
	CDR-H3	-	34
	-	CDR-L1	35
		CDR-L1 (bis)	60
	-	CDR-L2	36
		CDR-L2 (bis)	61
	-	CDR-L3	37
		CDR-L3 (bis)	62

Table 3b

Antibody Hz515H7	**Heavy chain**	**Light chain**	**SEQ ID NO.**
Variable Domains	VH1	-	38
	VH1 D76N	-	39
	VH1 V48L D76N	-	40
	VH2	-	41
	-	VL1	42
	-	VL1 T59A E61D	43
	-	VL2	44

	-	VL2.1	45
	-	VL2.2	46
	-	VL2.3	47
	-	VL3	48
Complete Sequences (without signal peptide)	VH1	-	49
	VH1 D76N	-	50
	VH1 V48L D76N	-	51
	VH2	-	52
	-	VL1	53
	-	VL1 T59A E61D	54
	-	VL2	55
	-	VL2.1	56
	-	VL2.2	57
	-	VL2.3	58
	-	VL3	59

Table 3c

Antibody Hz515H7-2	**Heavy chain**	**Light chain**	**SEQ ID NO.**
Variable Domains	VH1	-	93
	-	VL1	94
Complete Sequences (without signal peptide)	VH1	-	95
	-	VL1	96

The expression "optimized sequence" means that the codons encoding the amino acids constitutive of the protein of interest (herein the antibody variable domains) have been optimized for a better recognition by the translation machinery in a dedicated cell type, herewith mammalian cells. With this respect, the amino acid sequence of the given protein encoded by the optimized sequence is identical to that of the non-optimized sequence, but the nucleotide sequence is different. Optimization also include G/C content adaptation and prevention of stable RNA secondary structure (see as example Kim et al., 1997 Gene199(1-2):293-301).

For example, the nucleotide sequence of the murine CDR-H1 (SEQ ID No. 71) has been optimized and corresponds to the nucleotide sequence of the humanized CDR-H1 (SEQ ID No. 32) wherein the codons ggg, act and gat (coding for the residues Gly,

Thr and Asp, respectively) have been replaced by the codons ggc, acc and gac, respectively (also coding for the residue Gly, Thr and Asp, respectively).

Concerning CDR-H2 and CDR-H3 (SEQ ID Nos. 72 and 73, respectively), they have also been optimized and correspond to the optimized CDRs of SEQ ID Nos. 33 and 34, respectively.

It is the same for the three CDRs of the light chain (SEQ ID Nos. 74, 75 and 76, respectively) with two humanized optimized forms corresponding to the VL1, VL2 and VL3 (SEQ ID Nos. 35, 36 and 37, respectively) and to the VL2.1, VL2.2 and VL2.3 (SEQ ID Nos. 60, 61 and 62, respectively).

The following table 4 summarizes the original CDRs, i.e. the murine non optimized sequences.

Table 4

Antibody 515H7	**Heavy chain**	**Light chain**	**SEQ ID NO.**
murine CDR(s)	CDR-H1	-	71
	CDR-H2	-	72
	CDR-H3	-	73
	-	CDR-L1	74
	-	CDR-L2	75
	-	CDR-L3	76

The terms "nucleic acid", "nucleic sequence", "nucleic acid sequence", "polynucleotide", "oligonucleotide", "polynucleotide sequence" and "nucleotide sequence", used interchangeably in the present description, mean a precise sequence of nucleotides, modified or not, defining a fragment or a region of a nucleic acid, containing unnatural nucleotides or not, and being either a double-strand DNA, a single-strand DNA or transcription products of said DNAs.

It should also be included here that the present invention does not relate to nucleotide sequences in their natural chromosomal environment, i.e., in a natural state. The sequences of the present invention have been isolated and/or purified, i.e., they were sampled directly or indirectly, for example by a copy, their environment having been at least partially modified. Isolated nucleic acids obtained by recombinant

genetics, by means, for example, of host cells, or obtained by chemical synthesis should also be mentioned here.

"Nucleic sequences exhibiting a percentage identity of at least 80%, preferably 85%, 90%, 95% and 98%, after optimal alignment with a preferred sequence" means nucleic sequences exhibiting, with respect to the reference nucleic sequence, certain modifications such as, in particular, a deletion, a truncation, an extension, a chimeric fusion and/or a substitution, notably punctual. Preferably, these are sequences which code for the same amino acid sequences as the reference sequence, this being related to the degeneration of the genetic code, or complementarity sequences that are likely to hybridize specifically with the reference sequences, preferably under highly stringent conditions, notably those defined below.

Hybridization under highly stringent conditions means that conditions related to temperature and ionic strength are selected in such a way that they allow hybridization to be maintained between two complementarity DNA fragments. On a purely illustrative basis, the highly stringent conditions of the hybridization step for the purpose of defining the polynucleotide fragments described above are advantageously as follows.

DNA-DNA or DNA-RNA hybridization is carried out in two steps: (1) prehybridization at 42°C for three hours in phosphate buffer (20 mM, pH 7.5) containing 5X SSC (1X SSC corresponds to a solution of 0.15 M NaCl + 0.015 M sodium citrate), 50% formamide, 7% sodium dodecyl sulfate (SDS), 10X Denhardt's, 5% dextran sulfate and 1% salmon sperm DNA; (2) primary hybridization for 20 hours at a temperature depending on the length of the probe (i.e.: 42°C for a probe >100 nucleotides in length) followed by two 20-minute washings at 20°C in 2X SSC + 2% SDS, one 20–minute washing at 20°C in 0.1X SSC + 0.1% SDS. The last washing is carried out in 0.1X SSC + 0.1% SDS for 30 minutes at 60°C for a probe >100 nucleotides in length. The highly stringent hybridization conditions described above for a polynucleotide of defined size can be adapted by a person skilled in the art for longer or shorter oligonucleotides, according to the procedures described in Sambrook, *et al.* (Molecular cloning: a laboratory manual, Cold Spring Harbor Laboratory; 3rd edition, 2001).

The invention also relates to a vector comprising a nucleic acid as described in the invention.

The invention notably targets cloning and/or expression vectors that contain such a nucleotide sequence.

The vectors of the invention preferably contain elements which allow the expression and/or the secretion of nucleotide sequences in a given host cell. The vector thus must contain a promoter, translation initiation and termination signals, as well as suitable transcription regulation regions. It must be able to be maintained in a stable manner in the host cell and may optionally have specific signals which specify secretion of the translated protein. These various elements are selected and optimized by a person skilled in the art according to the host cell used. For this purpose, the nucleotide sequences can be inserted in self-replicating vectors within the chosen host or be integrative vectors of the chosen host.

Such vectors are prepared by methods typically used by a person skilled in the art and the resulting clones can be introduced into a suitable host by standard methods such as lipofection, electroporation, heat shock or chemical methods.

The vectors are, for example, vectors of plasmid or viral origin. They are used to transform host cells in order to clone or express the nucleotide sequences of the invention.

The invention also comprises host cells transformed by or comprising a vector as described in the present invention.

The host cell can be selected among prokaryotic or eukaryotic systems such as bacterial cells, for example, but also yeast cells or animal cells, notably mammal cells. Insect or plant cells can also be used.

The invention also relates to animals, other than man, that have a transformed cell according to the invention.

Another aspect of the invention relates to a method for the production of an antibody according to the invention, or one of its functional fragments, characterized in that said method comprises the following steps:

a) the culture in a medium of and the suitable culture conditions for a host cell according to the invention; and

b) the recovery of said antibody, or one of its functional fragments, thus produced from the culture medium or from said cultured cells.

The transformed cells according to the invention are of use in methods for the preparation of recombinant polypeptides according to the invention. Methods for the preparation of polypeptide according to the invention in recombinant form, characterized in that said methods use a vector and/or a cell transformed by a vector according to the invention, are also comprised in the present invention. Preferably, a cell transformed by a vector according to the invention is cultured under conditions that allow the expression of the aforesaid polypeptide and recovery of said recombinant peptide.

As already mentioned, the host cell can be selected among prokaryotic or eukaryotic systems. In particular, it is possible to identify the nucleotide sequences of the invention that facilitate secretion in such a prokaryotic or eukaryotic system. A vector according to the invention carrying such a sequence can thus be used advantageously for the production of recombinant proteins to be secreted. Indeed, the purification of these recombinant proteins of interest will be facilitated by the fact that they are present in the supernatant of the cellular culture rather than inside host cells.

The polypeptides of the invention can also be prepared by chemical synthesis. One such method of preparation is also an object of the invention. A person skilled in the art knows methods for chemical synthesis, such as solid-phase techniques (see notably Steward *et al.*, 1984, Solid phase peptides synthesis, Pierce Chem. Company, Rockford, 111, 2nd ed.) or partial solid-phase techniques, by condensation of fragments or by conventional synthesis in solution. Polypeptides obtained by chemical synthesis and capable of containing corresponding unnatural amino acids are also comprised in the invention.

The antibodies, or the derived compounds or functional fragments of same, likely to be obtained by the method of the invention are also comprised in the present invention.

According to still another aspect, the present invention relates to an antibody as described above, characterized in that it is, in addition, capable of specifically binding to a human chemokine family receptor and/or capable of specifically inhibiting the signaling of such a receptor.

According to a novel embodiment, the invention relates to an antibody, or its derived compounds or functional fragments, consisting of an antibody that is bispecific in the sense that it comprises a second motif capable of interacting with any receptor implicated in the development of tumors, such as, for example, VEGFR, VEGF, EGFR, IGF–1R, HER2neu, HGF, cMET, FGF, tetraspanins, integrins, CXCR4 (other than the antibody of the present invention, i.e. targeting another epitope), CXCR7 or CXCR2.

The bispecific or bifunctional antibodies constitute a second generation of monoclonal antibodies in which two different variable regions are combined in the same molecule (Hollinger and Bohlen, 1999, Cancer and metastasis, rev. 18:411-419). Their utility was demonstrated in both diagnostic and therapeutic domains relative to their capacity to recruit new effector functions or to target several molecules on the surface of tumor cells; such antibodies can be obtained by chemical methods (Glennie MJ *et al.*, 1987, J. Immunol. 139, 2367–2375; Repp R. *et al.*, 1995, J. Hemat., 377-382) or somatic methods (Staerz U.D. and Bevan M.J., 1986, PNAS 83, 1453-1457; Suresh M.R. *et al.*, 1986, Method Enzymol., 121:210-228) but also, preferentially, by genetic engineering techniques that make it possible to force heterodimerization and thus facilitate the purification of the antibody sought (Merchand *et al.*, 1998, Nature Biotech., 16:677-681).

These bispecific antibodies can be constructed as whole IgG, bispecific Fab'2, Fab'PEG, diabodies or bispecific scFv, but also as a tetravalent bispecific antibody in which two binding sites are present for each antigen targeted (Park *et al.*, 2000, Mol. Immunol., 37(18):1123-30) or the fragments of same as described above.

In addition to an economic advantage given that the production and administration of a bispecific antibody are cheaper than the production of two specific antibodies, the use of such bispecific antibodies has the advantage of reducing the treatment's toxicity. Indeed, the use of a bispecific antibody makes it possible to decrease the overall quantity of circulating antibodies and, consequently, possible toxicity.

In a preferred embodiment of the invention, the bispecific antibody is a bivalent or tetravalent antibody.

Lastly, the present invention relates to the antibody described above, or its derived compounds or functional fragments, for use as a drug.

The invention also relates to a pharmaceutical composition comprising as an active ingredient a compound consisting of an antibody of the invention, or one of its derived compounds or functional fragments. Preferably, said antibody is supplemented by an excipient and/or a pharmaceutically acceptable carrier.

The invention also relates to a composition characterized in that it comprises, in addition, as a combination product for use in a simultaneous, separated or extended fashion, an anti-tumor antibody other that an antibody directed against CXCR4.

According to still another embodiment, the present invention also relates to a pharmaceutical composition as described above that comprises at least a second antitumor compound selected among the compounds capable of specifically inhibiting the tyrosine kinase activity of receptors such as IGF-IR, EGFR, HER2/neu, cMET, VEGFR or VEGF, or any other antitumor compound known to a person skilled in the art.

In a second preferred aspect of the invention, said second compound can be selected among the antibodies antiEGFR, antiIGF-IR, antiHER2/neu, anticMET, VEGFR, VEGF, etc., isolated, or their functional fragments and derived compounds, capable of inhibiting the proliferative and/or anti-apoptotic and/or angiogenic and/or inductive activity of metastatic dissemination promoted by said receptors.

Also suitable for mention are antiCD20 antibodies such as a rituximab, ibritumomab or tositumomab; antiCD33 antibodies such as gemtuzumab or lintuzumab; antiCD22 antibodies such as epratuzumab; antiCD52 antibodies such as alemtuzumab; antiEpCAM antibodies such as edrecolomab, Ch 17-1A or IGN-101; antiCTP21 or 16 antibodies such as Xactin; antiDNA-Ag antibodies such as ^{131}I-Cotara TNT-1; antiMUC1 antibodies such as pemtumomab or R1150; antiMUC18 antibodies such as ABX-MA1; antiGD3 antibodies such as mitumomab; antiECA antibodies such as CeaVac or labetuzumab; antiCA125 antibodies such as OvaRex; antiHLA-DR antibodies such as apolizumab; antiCTLA4 antibodies such as MDX-010; antiPSMA antibodies such as MDX-070, ^{111}In & ^{90}Y-J591, ^{177}Lu J591, J591-DM1; antiLewis Y antibodies such as IGN311; antiangiogenesis antibodies such as AS1405 and 90YmuBC1; antiTrail-R1 antibodies such as TRAIL R1mAb or TRAIL R2mAb.

Another embodiment complementary to the invention consists of a composition as described above comprised of, in addition, as a combination or conjugaison product for simultaneous, separated or extended use, a cytotoxic/cytostatic agent.

"Simultaneous use" means the administration of both compounds of the composition comprised in a single dosage form.

"Separated use" means administration, at the same time, of both compounds of the composition, comprised in distinct dosage forms.

"Extended use" means the successive administration of both compounds of the composition, each comprised in a distinct dosage form.

Generally, the composition according to the invention considerably increases cancer treatment effectiveness. In other words, the therapeutic effect of the antibody of the invention is enhanced in an unexpected way by the administration of a cytotoxic agent. Another major subsequent advantage produced by a composition of the invention relates to the possibility of using lower effective doses of the active ingredient, thus making it possible to avoid or reduce the risks of the appearance of side effects, in particular the effect of the cytotoxic agent. Moreover, this composition makes it possible to achieve the expected therapeutic effect more quickly.

"Therapeutic anticancer agent" or "cytotoxic agent" means a substance which, when it is administered to a patient, treats or prevents the development of cancer in the patient. Non-limiting examples of such agents include "alkylating" agents, antimetabolites, antitumor antibiotics, mitotic inhibitors, inhibitors of chromatin functioning, antiangiogenics, antiestrogens, antiandrogens and immunomodulators.

Such agents, for example, are cited in VIDAL, on the page devoted to compounds related to oncology and hematology under the heading "Cytotoxic"; the cytotoxic compounds cited by reference to this document are cited herein as preferred cytotoxic agents.

"Alkylating agent" refers to any substance that can bind covalently with or can alkylate any molecule, preferentially a nucleic acid (e.g., DNA), within a cell. Examples of such alkylating agents include nitrogen mustards such as mechlorethamine, chlorambucil, melphalan, chlorhydrate, pipobroman, prednimustine, disodium phosphate or estramustine; oxazaphosphorines such as cyclophosphamide, altretamine, trofosfamide, sulfofosfamide or ifosfamide; aziridines or ethylene-imines such as

thiotepa, triethyleneamine or altetramine; nitrosoureas such as carmustine, streptozocine, fotemustine or lomustine; alkyl sulfonates such as busulfan, treosulfan or improsulfan; triazenes such as dacarbazine; or platinum complexes such as cisplatine, oxaliplatine or carboplatine.

"Antimetabolite" refers to a substance that blocks growth and/or cellular metabolism by interfering with certain activities, generally DNA synthesis. Examples of antimetabolites include methotrexate, 5-fluorouracile, floxuridine, 5-fluorodeoxyuridine, capecitabine, cytarabine, fludarabine, cytosine arabinoside, 6-mercaptopurine (6-MP), 6-thioguanine (6-TG), chlorodesoxyadenosine, 5-azacytidine, gemcitabine, cladribine, deoxycoformycin and pentostatin.

"Antitumor antibiotic" refers to a compound that can prevent or inhibit the synthesis of DNA, RNA and/or proteins. Examples of such antitumor antibiotics include doxorubicin, daunorubicin, idarubicin valrubicin, mitoxantrone, dactinomycin, mithramycin, plicamycin, mitomycin C, bleomycin and procarbazine.

"Mitotic inhibitors" prevent the normal progression of the cell cycle and mitosis. In general, microtubule inhibitors or "taxoids" such as paclitaxel and docetaxel are capable of inhibiting mitosis. The vinca alkaloids, such as vinblastine, vincristine, vindesine and vinorelbine, are also capable of inhibiting mitosis.

"Chromatin inhibitors" or "topoisomerase inhibitors" are substances that inhibit the normal functioning of proteins that shape chromatin, such as topoisomerases I and II. Examples of such inhibitors include, for topoisomerase I, camptothecine and its derivatives, such as irinotecan or topotecan; for topoisomerase II, etoposide, etiposide phosphate and teniposide.

An "antiangiogenic" is any drug, compound, substance or agent that inhibits the growth of the blood vessels. Examples of antiangiogenics include, without being limiting, razoxin, marimastat, batimastat, prinomastat, tanomastat, ilomastat, CGS-27023A, halofuginone, COL-3, neovastat, BMS-275291, thalidomide, CDC 501, DMXAA, L-651582, squalamine, endostatine, SU5416, SU6668, interferon-alpha, EMD121974, interleukin-12, IM862, angiostatin and vitaxin.

"Antiestrogen" or "estrogen antagonist" refers to any substance that decreases, antagonizes or inhibits estrogen action. Examples of such agents are tamoxifene, toremifene, raloxifene, droloxifene, iodoxyfene, anastrozole, letrozole and exemestane.

"Antiandrogen" or "androgen antagonist" refers to any substance that reduces, antagonizes or inhibits androgen action. Examples of antiandrogens include flutamide, nilutamide, bicalutamide, sprironolactone, cyproterone acetate, finasteride and cimitidine.

Immunomodulators are substances that stimulate the immune system. Examples of immunomodulators include interferon, interleukins such as aldesleukin, OCT-43, denileukin diftitox or interleukine-2, tumor necrosis factors such as tasonermine, or other types of immunomodulators such as lentinan, sizofiran, roquinimex, pidotimod, pegademase, thymopentine, poly I:C or levamisole in combination with 5-fluorouracil.

For further details, a person skilled in the art can refer to the manual published by the French Association of Therapeutic Chemistry Teachers titled "Therapeutic chemistry, vol. 6, Antitumor drugs and perspectives in the treatment of cancer, TEC and DOC edition, 2003 [in French]".

In a particularly preferred embodiment, said composition of the invention as a combination product is characterized in that said cytotoxic agent is bound chemically to said antibody for use simultaneously.

In a particularly preferred embodiment, said composition is characterized in that said cytotoxic/cytostatic agent is selected among the spindle inhibitors or stabilizers, preferably vinorelbine and/or vinflunine and/or vincristine.

In order to facilitate binding between said cytotoxic agent and the antibody according to the invention, spacer molecules can be introduced between the two compounds to bind, such as the poly(alkylene)glycol polyethyleneglycol or the amino acids; or, in another embodiment, said cytotoxic agents' active derivatives, into which have been introduced functions capable of reacting with said antibody, can be used. These binding techniques are well-known to a person skilled in the art and will not be discussed in more detail in the present description.

Other EGFR inhibitors include, without being limiting, monoclonal antibodies C225 and antiEGFR 22Mab (ImClone Systems Incorporated), ABX-EGF (Abgenix/Cell Genesys), EMD-7200 (Merck KgaA) or compounds ZD-1834, ZD-1838 and ZD-1839 (AstraZeneca), PKI-166 (Novartis), PKI-166/CGP-75166 (Novartis), PTK 787 (Novartis), CP 701 (Cephalon), flunomide (Pharmacia/Sugen), CI–1033 (Warner Lambert Parke Davis), CI-1033/PD 183, 805 (Warner Lambert Parke Davis), CL-387,

785 (Wyeth-Ayerst), BBR–1611 (Boehringer Mannheim GMBH/Roche), Naamidine A (Bristol-board Myers Squibb), RC-3940-II (Pharmacia), BIBX-1382 (Boehringer Ingelheim), OLX–103 (Merck & Co), VRCTC–310 (Ventech Research), EGF fusion toxin (Seragen Inc.), DAB-389 (Seragen/Lilgand), ZM–252808 (Imperial Cancer Research Fund), RG-50864 (INSERM), LFM-A12 (Parker Hughes Center Cancer), WHI–P97 (Parker Hughes Center Cancer), GW-282974 (Glaxo), KT–8391 (Kyowa Hakko) or the "EGFR vaccine" (York Medical/Centro of Immunologia Molecular).

Another aspect of the invention relates to a composition characterized in that at least one of said antibodies, or of the derived compounds or functional fragments of same, is combined or conjugated with a cellular toxin and/or a radioisotope.

Preferably, said toxin or said radioisotope is capable of preventing the growth or proliferation of the tumor cell, notably of completely inactivating said tumor cell.

Also preferably, said toxin is an enterobacteria toxin, notably *Pseudomonas* exotoxin A.

The radioisotopes preferentially combined with therapeutic antibodies are radioisotopes that emit gamma rays, preferentially iodine^{131}, yttrium^{90}, gold^{199}, palladium^{100}, copper^{67}, bismuth^{217} and antimony^{211}. Radioisotopes that emit alpha and beta rays can also be used in therapy.

"Toxin or radioisotope combined with at least one antibody of the invention, or a functional fragment of same" refers to any means that makes it possible to bind said toxin or said radioisotope to that at least one antibody, notably by covalent binding between the two compounds, with or without the introduction of the binding molecule.

Examples of agents that allow chemical (covalent), electrostatic, or non-covalent bonding of all or part of the conjugate's elements include, in particular, benzoquinone, carbodiimide and more particularly EDC (1-ethyl-3-[3-dimethyl-aminopropyl]-carbodiimide-hydrochloride), dimaleimide, dithiobis-nitrobenzoic (DTNB) acid, N-succinimidyl S-acetyl thio-acetate (SATA), bridging agents with one or more groups, with one or more phenylaside groups, reacting with ultraviolet (UV) rays, most preferentially N-[-4 (azidosalicylamino)butyl]-3'-(2'-pyridyldithio)-propionamide (APDP), N-succinimid-yl 3(2-pyridyldithio) propionate (SPDP) and 6-hydrazino-nicotinamide (HYNIC).

Another form of binding, notably for radioisotopes, can consist of the use of bifunctional ion chelating agents.

Examples of such chelators include the chelators derived from EDTA (ethylenediaminetetraacetic acid) or DTPA (diethylenetriaminepentaacetic acid) which were developed to bind metals, particularly radioactive metals, with immunoglobulins. Thus, DTPA and its derivatives can be substituted on the carbon chain by various groups in such a way as to increase the stability and the rigidity of the ligand-metal complex (Krejcarek *et al.*, 1977; Brechbiel *et al.*, 1991; Gansow, 1991; US patent 4,831,175).

For example, DTPA (diethylenetriaminepentaacetic acid) and its derivatives, which long have been widely used in drug and biology either in its free form or in a complex with a metal ion, exhibit the remarkable characteristic of forming stable chelates with metal ions which can be coupled with proteins of therapeutic or diagnostic interest, such as antibodies, for the development of radio-immuno conjugates for cancer therapy (Meases *et al.*, 1984; Gansow *et al.*, 1990).

Also preferably, said at least one antibody of the invention forming said conjugate is selected among its functional fragments, notably fragments that have lost their Fc component, such as scFv fragments.

The present invention also comprises the use of the composition for the preparation of a drug intended for the prevention or the treatment of cancer.

The present invention also relates to the use of an antibody, or a derived compound or functional fragment of same, preferably humanized, and/or of a composition according to the invention for the preparation of a drug for inhibiting the growth of tumor cells. Generally, the present invention relates to the use of an antibody, or a derived compound or functional fragment of same, preferably humanized, and/or of a composition, for the preparation of a drug for cancer prevention or treatment.

Preferred cancers that can be prevented and/or treated include prostate cancer, osteosarcoma, lung cancer, breast cancer, endometrial cancer, colon cancer, multiple myeloma, ovarian cancer, pancreatic cancer or any other cancer.

The invention also concerns the use of an antibody, or a derived compound or functional fragment of same, and/or of a composition as above described for the preparation of a drug for modulating CXCR4 activity in a cell.

Another aspect of the present invention relates to the use of the antibody as described in a diagnostic method, preferably *in vitro*, of diseases related to CXCR4 expression level. Preferably, said CXCR4 protein related diseases in said diagnostic method will be cancers.

Thus, the antibodies of the invention, or the derived compounds or functional fragments of same, can be employed in a method for the detection and/or quantification of CXCR4 protein in a biological sample *in vitro*, notably for the diagnosis of diseases associated with an abnormal expression with this protein, such as cancers, wherein said method comprises the following steps:

a) placing the biological sample in contact with an antibody according to the invention, or a derived compound or functional fragment of same;

b) demonstrating the antigen-antibody complex possibly formed.

Thus, the present invention also comprises the kits or accessories for the implementation of a method as described, comprising the following elements:

a) a polyclonal or monoclonal antibody of the invention;

b) optionally, reagents for constituting the medium favorable to immunological reactions;

c) optionally, reagents that reveal the antigen-antibodies complexes produced by the immunological reaction.

In a general way, the present invention relates to the use of an antibody, or a derived compound or functional fragment of same, comprising a heavy chain comprising the following three CDRs, respectively CDR-H1, CDR-H2 and CDR-H3 of sequences SEQ ID Nos. 4, 5 and 6 ; and a light chain comprising the following three CDRs, respectively CDR-L1, CDR-L2 and CDR-L3 of sequences SEQ ID Nos. 7, 8, 9, for diagnosing in vitro an oncogenic disorder associated with expression of CXCR4 or determining in vitro the prognosis for developing an oncogenic disorder associated with expression of CXCR4.

Concerning this aspect, the present invention is particularly directed to the use of humanized antibody heavy chain and/or a humanized antibody light chain and/or a humanized antibody, or a derived compound or functional fragment of same, according to the invention for diagnosing in vitro an oncogenic disorder associated with

expression of CXCR4 or determining in vitro the prognosis for developing an oncogenic disorder associated with expression of CXCR4.

In another aspect the present invention is directed to a process of detecting in vitro the presence and/or the location of a CXCR4 expressing tumor in a subject, wherein said process comprises the steps of (a) contacting a sample from the subject with an antibody, or a derived compound or functional fragment of same, comprising a heavy chain comprising the following three CDRs, respectively CDR-H1, CDR-H2 and CDR-H3 of sequences SEQ ID No. 4, 5 and 6; and a light chain comprising the following three CDRs, respectively CDR-L1, CDR-L2 and CDR-L3 of sequences SEQ ID Nos. 7, 8, 9, and (b) detecting the binding of said antibody with the sample.

Particularly, the present invention is directed to a process of detecting in vitro the presence and/or the location of a CXCR4 expressing tumor in a subject, wherein said process comprises the steps of:

(a) contacting a sample from the subject with a humanized antibody heavy chain and/or a humanized antibody light chain and/or a humanized antibody, or a derived compound or functional fragment of same, according to the invention; and

(b) detecting the binding of said antibody with the sample.

As non limitative example, such detection can be done by FACS, or any other technique known by the man skilled in the art.

In another aspect the present invention is directed to a process of determining in vitro the expression level of CXCR4 in a CXCR4 expressing tumor from a subject, wherein said process comprises the steps of (a') contacting a sample from the subject with an antibody, or a derived compound or functional fragment of same, comprising a heavy chain comprising the following three CDRs, respectively CDR-H1, CDR-H2 and CDR-H3 of sequences SEQ ID Nos. 4, 5 and 6; and a light chain comprising the following three CDRs, respectively CDR-L1, CDR-L2 and CDR-L3 of sequences SEQ ID Nos. 7, 8, 9, and (b') quantifying the level of antibody binding to CXCR4 in said sample.

Particularly, the present invention is directed to a process of determining in vitro the expression level of CXCR4 in a CXCR4 expressing tumor from a subject, wherein said process comprises the steps of:

(a') contacting a sample from the subject with a humanized antibody heavy chain and/or a humanized antibody light chain and/or a humanized antibody, or a derived compound or functional fragment of same, according to the invention; and

(b') quantifying the level of antibody binding to CXCR4 in said sample.

In a preferred embodiment, the CXCR4 expression level is measured by immunohistochemistry (IHC).

In another aspect, the present invention relates to a process of diagnosing in vitro a CXCR4 expressing tumor or determining in vitro the prognosis for developing a CXCR4 expressing tumor in a subject, wherein said process comprises the steps of (i) determining the expression level of CXCR4 according to the present invention, particularly involving humanized antibodies of the present invention, and (ii) comparing the expression level of step (i) with a reference expression level of CXCR4 from normal tissue.

In another aspect, the present invention relates to a process of determining in vitro the CXCR4 status of a tumor of a subject, wherein said process comprises the steps of (1) determining the expression level of CXCR4 according to the present invention, particularly involving humanized antibodies of the present invention, (2) scoring said tumor for CXCR4 expression level, and (3) comparing said scoring to that obtained from a control sample.

In another aspect, the present invention relates to a process of determining whether an oncogenic disorder is susceptible to treatment with an anti-CXCR4 antibody, or a fragment or derivative thereof, wherein said process comprises the steps of:

(a) determining in vitro the CXCR4 status of a tumor of a subject according to the invention; and

(b) determining that, if the status is CXCR4(+), the oncogenic disorder is susceptible to treatment with an anti-CXCR4 antibody, or a fragment or derivative thereof.

In another aspect, the present invention relates to a process for the screening and/or the identification of molecules as CXCR4 antagonist anti-tumoral agents comprising the steps of:

a) selecting cells expressing CXCR4,

b) incubating said cells with an antibody, or a derived compound or functional fragment of same, comprising a heavy chain comprising the following three CDRs, respectively CDR-H1, CDR-H2 and CDR-H3 of sequences SEQ ID Nos. 4, 5 and 6; and a light chain comprising the following three CDRs, respectively CDR-L1, CDR-L2 and CDR-L3 of sequences SEQ ID Nos. 7, 8, 9, and

c) evaluating the tested molecules for their potential inhibition of the binding between the antibody, or one of its functional fragments or derivatives, to CXCR4, and

d) selecting molecules capable of said inhibition.

In this aspect, the present invention relates particularly to a process for the screening and/or the identification of molecules as CXCR4 antagonist anti-tumoral agents comprising the steps of:

a) selecting cells expressing CXCR4,

b) incubating said cells with a humanized antibody heavy chain and/or a humanized antibody light chain and/or a humanized antibody, or a derived compound or functional fragment of same, according to the invention, and

c) evaluating the tested molecules for their potential inhibition of the binding between the antibody, or one of its functional fragments or derivatives, to CXCR4, and

d) selecting molecules capable of said inhibition.

In another aspect, the present invention relates to a kit comprising at least an antibody, or a derived compound or functional fragment of same, comprising a heavy chain comprising the following three CDRs, respectively CDR-H1, CDR-H2 and CDR-H3 of sequences SEQ ID Nos. 4, 5 and 6; and a light chain comprising the following three CDRs, respectively CDR-L1, CDR-L2 and CDR-L3 of sequences SEQ ID Nos. 7, 8, 9, said antibody being preferably labeled.

In this aspect, the present invention relates particularly to a kit comprising at least a humanized antibody heavy chain and/or a humanized antibody light chain and/or a humanized antibody, or a derived compound or functional fragment of same, according to the invention, said antibody being preferably labeled.

In another aspect, the present invention relates to a kit according to the present invention for determining in vitro the CXCR4 status of a tumor, said kit further comprising:

i) a reagent useful for detecting the extent of binding between the said anti-CXCR4 antibody and CXCR4; and

ii) positive and negative control samples useful for the scoring the CXCR4 expression level.

Advantageously, the antibodies or functional fragments of same can be immobilized on a support, notably a protein chip. One such protein chip is an object of the invention.

Advantageously, the protein chips can be used in the kits or accessories required for detecting and/or quantifying CXCR4 protein in a biological sample.

It must be stated that the term "biological sample" relates herein to samples taken from a living organism (notably blood, tissue, organ or other samples taken from a mammal, notably man) or any sample likely to contain one such CXCR4 protein (such as a sample of cells, transformed if needed).

Said antibody, or a functional fragment of same, can be in the form of an immunoconjugate or of a labeled antibody in order to obtain a detectable and/or quantifiable signal.

The labeled antibodies of the invention, or the functional or fragments of same, include, for example, antibody conjugates (immunoconjugates), which can be combined, for example, with enzymes such as peroxidase, alkaline phosphatase, α-D-galactosidase, glucose oxidase, glucose amylase, carbonic anhydrase, acetyl-cholinesterase, lysozyme, malate dehydrogenase or glucose-6 phosphate dehydrogenase or by a molecule such as biotin, digoxigenin or 5-bromo-desoxyuridine. Fluorescent labels can be also combined with the antibodies of the invention or functional fragments of same, including notably fluorescein and its derivatives, fluorochrome, rhodamine and its derivatives, green fluorescent protein (GFP), dansyl, umbelliferone, etc. In such conjugates, the antibodies of the invention or functional fragments of same can be prepared by methods known to a person skilled in the art. They can be bound with enzymes or fluorescent labels directly; via a spacer group or a linkage group such as polyaldehyde, glutaraldehyde, ethylenediaminetetraacetic acid (EDTA) or diethylenetriaminepentaacetic acid (DPTA); or in the presence of binding agents such as

those mentioned above for therapeutic conjugates. Conjugates carrying fluorescein labels can be prepared by reaction with an isothiocyanate.

Others conjugates can also include chemiluminescent labels such as luminol and dioxetane, bioluminescent labels such as luciferase and luciferin, or radioactive labels such as iodine^{123}, iodine^{125}, iodine^{126}, iodine^{133}, bromine^{77}, technetium^{99m}, indium^{111}, indium^{113m}, gallium^{67}, gallium^{68}, ruthenium^{95}, ruthenium^{97}, ruthenium^{103}, ruthenium^{105}, mercury^{107}, mercury^{203}, rhenium^{99m}, rhenium^{101}, rhenium^{105}, scandium^{47}, tellurium^{121m}, tellurium^{122m}, tellurium^{125m}, thulium^{165}, thulium^{167}, thulium^{168}, fluorine^{18}, yttrium^{199} and iodine^{131}. Existing methods known to a person skilled in the art for binding radioisotopes with antibodies, either directly or via a chelating agent such as the EDTA or DTPA mentioned above, can be used for as diagnostic radioisotopes. Thus should be mentioned labeling with [I^{125}]Na by the chloramine-T technique [Hunter W.M. and Greenwood F.C. (1962) Nature 194:495]; labeling with technetium^{99m} as described by Crockford *et al.* (US patent 4,424,200) or bound via DTPA as described by Hnatowich (US patent 4,479,930).

The use of the antibody of the invention as biomarker is also disclosed. The methods may be used for detecting or diagnosing various hyperproliferative oncogenic disorders associated with expression of CXCR4 exemplified by, but not limited to breast cancer, ovarian cancer, prostate cancer, pancreatic cancer, skin cancers, oesophageal cancer, lung cancer, head and neck cancer, bladder cancer, colorectal cancer, osteosarcomas, neuroblastoma, acute lymphoblastic leukemia, Acute myeloid leukemia, chronic myeloid leukemia, chronic lymphocytic leukemia, multiple myeloma, lymphomas, renal cancer, glioblastoma, thyroid cancer, rhabdomyosarcoma, or any other cancer associated with expression of CXCR4. As would be recognized by one of ordinary skill in this art, the level of antibody expression associated with a particular disorder will vary depending on the nature and/or the severity of the pre-existing condition.

Administration of the antibodies of the present invention in any of the conventional ways known to one skilled in the art (e.g., topical, parenteral, intramuscular, etc.), will provide an extremely useful method of detecting dysplastic cells in a sample as well as allowing a clinician to monitor the therapeutic regiment of a

patient undergoing treatment for a hyperproliferative disorder associated with or mediated by expression of CXCR4.

In another embodiment, the invention relates to a pharmaceutical composition for in vivo imaging of an oncogenic disorder associated with expression of CXCR4 comprising the above monoclonal antibody or fragment thereof which is labeled and which binds CXCR4 in vivo; and a pharmaceutically acceptable carrier.

The antibody of the invention, or a functional fragment or derivative thereof, will find use in various medical or research purposes, including the detection, diagnosis, and staging of various pathologies associated with expression of CXCR4.

Stage determination has potential prognostic value and provides criteria for designing optimal therapy [Simpson et al. J. Clin. Oncology 18:2059 (2000)]. Generally, pathological staging of breast cancer for example, is preferable to clinical staging because the former gives a more accurate prognosis. However, clinical staging would be preferred if it were as accurate as pathological staging because it does not depend on an invasive procedure to obtain tissue for pathological evaluation.

When used with suitable labels or other appropriate detectable biomolecule or chemicals, the antibody of the invention is particularly useful for in vitro and in vivo diagnostic and prognostic applications.

Labels for use in immunoassays are generally known to those skilled in the art and include enzymes, radioisotopes, and fluorescent, luminescent and chromogenic substances, including colored particles such as colloidal gold or latex beads. Suitable immunoassays include enzyme-linked immunosorbent assays (ELISA). Various types of labels and methods of conjugating the labels to the antibodies of the invention are well known to those skilled in the art, such as the ones set forth below.

As used herein, the term "an oncogenic disorder associated with expression of CXCR4" is intended to include diseases and other disorders in which the presence of high levels or abnormally low levels of CXCR4 (aberrant) in a subject suffering from the disorder has been shown to be or is suspected of being either responsible for the pathophysiology of the disorder or a factor that contributes to a worsening of the disorder. Alternatively, such disorders may be evidenced, for example, by an increase in the levels of CXCR4 on the cell surface in the affected cells or tissues of a subject suffering from the disorder. The increase in CXCR4 levels may be detected, for

example, using the antibody 515H7 or hz515H7 of the invention. More, it refers to cells which exhibit relatively autonomous growth, so that they exhibit an aberrant growth phenotype characterized by a significant loss of control of cell proliferation. Alternatively, the cells may express normal levels of CXCR4 but are marked by abnormal proliferation.

In certain embodiments, "increased expression" as it relates to CXCR4 refers to protein or gene expression levels that demonstrate a statistically significant increase in expression (as measured by RNA expression or protein expression) relative to a control.

More particularly, it is considered the use of an antibody, or a functional fragment or derivative thereof, according to the invention as described, for diagnosing in vitro an oncogenic disorder associated with expression of CXCR4 or determining in vitro the prognosis for developing an oncogenic disorder associated with expression of CXCR4, for example a cancer associated with expression of CXCR4.

Another broad aspect in accordance with the invention concerns a method of diagnosing pathological hyperproliferative oncogenic disorder or a susceptibility to a pathological condition associated with expression of CXCR4 in a subject comprising determining the presence or absence of CXCR4 bearing cells in a sample, and diagnosing a pathological condition or susceptibility to a pathological condition based on the presence or absence of said CXCR4 bearing cells. The diagnostic uses of the antibody of the invention comprise primary tumors, cancers metastases, cancer stem cells. The antibody can be present in the form of an immunoconjugate or of a labeled antibody as to obtain a detectable and/or quantifiable signal.

More particularly, an preferred subject in accordance with the invention is a process of detecting in vitro the presence and/or the location of a CXCR4 expressing tumor in a subject, wherein said process comprises the steps of (a) contacting a sample from the subject with an antibody, or a functional fragment or derivative thereof, according to the invention, and (b) detecting the binding of said antibody with the sample. Another aspect of the subject is the follow-up of CXCR4 expression as a response to a CXCR4 targeted therapy during clinical trials, and more particularly when the downregulation and or degradation of the CXCR4 receptor is one of the component of the mechanism of action of the tested compound.

As will be apparent to the skilled artisan, the detection of the binding of the antibody of the invention may be revealed by various assays. Although any means for carrying out the assays is compatible with the invention, it can be mentioned, as examples, FACS, ELISA or IHC.

As used herein, the term "sample" is intended to mean any biological fluid, cell, tissue, organ or portion thereof, that includes or potentially includes a neoplastic cell, such as a cell from the colon, gastric, rectum, breast, ovary, prostate, kidney, lung, blood, brain, skin, thyroid, lymph node, bone marrow or other organ or tissue that contains or is suspected to contain a neoplastic cell. The term includes samples present in an individual as well as samples obtained or derived from the individual. For example, a sample can be a histologic section of a specimen obtained by biopsy, or cells that are placed in or adapted to tissue culture. A sample further can be a subcellular fraction or extract, or a crude or substantially pure nucleic acid molecule or protein preparation.

Clinical sample is intended to encompass a variety of sample types obtained from a subject and useful in the procedure of the invention, such as for example, a diagnostic or monitoring test of determining or detecting CXCR4 expression levels. The definition encompasses solid tissue samples obtained by surgical removal, a pathology specimen, an archived sample, or a biopsy specimen, tissue cultures or cells derived therefrom and the progeny thereof, and sections or smears prepared from any of these sources. Non-limiting examples are samples obtained from colon, gastric, rectum, breast, ovary, prostate, kidney, lung, blood, brain, skin, thyroid, lymph node, bone marrow etc. The definition also encompasses liquid samples of biologic origin, and may refer to either the cells or cell fragments suspended therein, or to the liquid medium and its solutes.

Another aspect in accordance with the invention relates to a process of determining in vitro the expression level of CXCR4 in a CXCR4 expressing tumor from a subject, wherein said process comprises the steps of (a') contacting a sample from the subject with an antibody, or a functional fragment or derivative thereof, according to the invention, and (b') quantifying the level of antibody binding to CXCR4 in said sample.

As will be apparent to the skilled artisan, the level of antibody binding to CXCR4 may be quantified in a number of ways such as by various assays. Although

any means for carrying out the assays is compatible with the invention, a preferred method brings into play immunoenzymatic processes according to the ELISA technique, by immunofluorescence, by immunohistochemistry or radio-immunoassay (RIA) technique or equivalent.

Preferably, the biological sample is formed by a biological fluid, such as serum, whole blood, cells, a tissue sample or biopsies of human origin. The sample, may for example include, biopsied tissue, which can be conveniently assayed for the presence of a pathological hyperproliferative oncogenic disorder associated with expression of CXCR4.

Once a determination is made of the amount of CXCR4 present in the test sample, the results can be compared with those of control samples, which are obtained in a manner similar to the test samples but from individuals that do not have or present with a hyperproliferative oncogenic disorder associated with expression of CXCR4. If the level of the CXCR4 is significantly elevated in the test sample, it may be concluded that there is an increased likelihood of the subject from which it was derived has or will develop said disorder.

The invention relates, more particularly, to a process of diagnosing in vitro a CXCR4 expressing tumor or determining in vitro the prognosis for developing a CXCR4 expressing tumor in a subject, wherein said process comprises the steps of (i) determining the expression level of CXCR4 as above described, and (ii) comparing the expression level of step (i) with a reference expression level of CXCR4 from normal tissue or a non expressing CXCR4 tissue.

"Diagnosing" a disease as used in the application is intended to include, for example, diagnosing or detecting the presence of a pathological hyperproliferative oncogenic disorder associated with or mediated by expression of CXCR4, monitoring the progression of the disease, and identifying or detecting cells or samples that are indicative of a disorder associated with the expression of CXCR4.

"Prognosis" as used in this application means the likelihood of recovery from a disease or the prediction of the probable development or outcome of a disease. For example, if a sample from a subject is positive for staining with the antibody of the invention, then the "prognosis" for that subject is better than if the sample was negative

for CXCR4 staining. Samples may be scored for CXCR4 expression levels on an appropriate scale as it will be more detailed hereinafter.

However another aspect of the invention is also related to the monitoring of CXCR4 expression for therapeutic compounds that induce a degradation of CXCR4 as one of their mechanisms of action. In that case following CXCR4 expression on cell membrane could be a critical tool to evaluate the efficacy of the treatment during clinical trials and "personalized" therapies.

The expression level of CXCR4 is advantageously compared or measured in relation to levels in a control cell or sample also referred to as a "reference level" or "reference expression level". "Reference level", "reference expression level", "control level" and "control" are used interchangeably in the specification. Broadly speaking, a "control level" means a separate baseline level measured in a comparable control cell, which is generally disease or cancer free. It may be from the same individual or from another individual who is normal or does not present with the same disease from which the diseased or test sample is obtained. Within the context of the present invention, the term "reference level" refers to a "control level" of expression of CXCR4 used to evaluate a test level of expression of CXCR4 in a cancer cell-containing sample of a patient. For example, when the level of CXCR4 in the biological sample of a patient is higher than the reference level of CXCR4, the cells will be considered to have a high level of expression, or overexpression, of CXCR4. The reference level can be determined by a plurality of methods. Expression levels may thus define CXCR4 bearing cells or alternatively the level of expression of CXCR4 independent of the number of cells expressing CXCR4. Thus the reference level for each patient can be proscribed by a reference ratio of CXCR4, wherein the reference ratio can be determined by any of the methods for determining the reference levels described herein.

For example, the control may be a predetermined value, which can take a variety of forms. It can be a single cut-off value, such as a median or mean. The "reference level" can be a single number, equally applicable to every patient individually, or the reference level can vary, according to specific subpopulations of patients. Thus, for example, older men might have a different reference level than younger men for the same cancer, and women might have a different reference level than men for the same cancer. Alternatively, the "reference level" can be determined by measuring the level of

expression of CXCR4 in non-oncogenic cancer cells from the same tissue as the tissue of the neoplastic cells to be tested. As well, the "reference level" might be a certain ratio of CXCR4 in the neoplastic cells of a patient relative to the CXCR4 levels in non-tumor cells within the same patient. The "reference level" can also be a level of CXCR4 of in vitro cultured cells, which can be manipulated to simulate tumor cells, or can be manipulated in any other manner which yields expression levels which accurately determine the reference level. On the other hand, the "reference level" can be established based upon comparative groups, such as in groups not having elevated CXCR4 levels and groups having elevated CXCR4 levels. Another example of comparative groups would be groups having a particular disease, condition or symptoms and groups without the disease. The predetermined value can be arranged, for example, where a tested population is divided equally (or unequally) into groups, such as a low-risk group, a medium-risk group and a high-risk group or into quandrants or quintiles, the lowest quandrant or quintile being individuals with the lowest risk or highest amount of CXCR4 and the highest quandrant or quintile being individuals with the highest risk or lowest amount of CXCR4.

The reference level can also be determined by comparison of the level of CXCR4 in populations of patients having the same cancer. This can be accomplished, for example, by histogram analysis, in which an entire cohort of patients are graphically presented, wherein a first axis represents the level of CXCR4, and a second axis represents the number of patients in the cohort whose tumor cells express CXCR4 at a given level. Two or more separate groups of patients can be determined by identification of subsets populations of the cohort which have the same or similar levels of CXCR4. Determination of the reference level can then be made based on a level which best distinguishes these separate groups. A reference level also can represent the levels of two or more markers, one of which is CXCR4. Two or more markers can be represented, for example, by a ratio of values for levels of each marker.

Likewise, an apparently healthy population will have a different 'normal' range than will have a population which is known to have a condition associated with expression of CXCR4. Accordingly, the predetermined value selected may take into account the category in which an individual falls. Appropriate ranges and categories can be selected with no more than routine experimentation by those of ordinary skill in the

art. By "elevated" "increased" it is meant high relative to a selected control. Typically the control will be based on apparently healthy normal individuals in an appropriate age bracket.

It will also be understood that the controls according to the invention may be, in addition to predetermined values, samples of materials tested in parallel with the experimental materials. Examples include tissue or cells obtained at the same time from the same subject, for example, parts of a single biopsy, or parts of a single cell sample from the subject.

In the clinical diagnosis or monitoring of patients with a CXCR4 mediated diseases, the detection of CXCR4 expressing cells or an increase in the levels of CXCR4, in comparison to the levels in a corresponding biological sample from a normal subject or non-cancerous tissue is generally indicative of a patient with or suspected of presenting with a CXCR4 mediated disorder.

In accordance with the above, the invention provides for a method for predicting susceptibility to cancer comprising detecting the expression level of CXCR4 in a tissue sample, its presence indicating susceptibility to cancer, wherein the degree of CXCR4 expression correlates to the degree of susceptibility. Thus, in specific embodiments, the expression of CXCR4 in, for example, breast tissue ovarian tissue, prostate tissue, pancreatic tissue, skin tissue, oesophageal tissue, lung tissue, head and neck tissue, bladder tissue, colorectal tissue, osteosarcoma tissue, neuroblastoma tissue, acute lymphoblastic leukemia cells, acute myeloid leukemia cells, chronic myeloid leukemia cells, chronic lymphocytic leukemia cells, multiple myeloma cells, lymphoma cells, renal tissue, glioblastoma tissue, thyroid tissue, rhabdomyosarcoma tissue, or any other tissue suspected of cells expressing CXCR4 is examined, with the presence of CXCR4 in the sample providing an indication of cancer susceptibility or the emergence or existence of a tissue specific tumor.

A method for evaluating tumor aggressiveness is also provided. In one embodiment, a method for observing the progression of a malignancy in an individual over time comprises determining the level of CXCR4 expressed by cells in a sample of the tumor, comparing the level so determined to the level of CXCR4 expressed in an equivalent tissue sample taken from the same individual at a different time, wherein the

degree of CXCR4 expression in the tumor sample over time provides information on the progression of the cancer.

In yet another embodiment, the application provides methods for determining the appropriate therapeutic protocol for a subject.

The presence or absence or a change in the level of CXCR4 in accordance with the invention may be indicative that the subject is likely to have a relapse or a progressive, or a persistent cancer associated with CXCR4. Thus, by measuring an increase in the number of cells expressing CXCR4 or changes in the concentration of CXCR4 present in various tissues or cells, it is possible to determine whether a particular therapeutic regimen aimed at ameliorating a malignancy associated with CXCR4 is effective.

Another subject of the invention is an in vivo method of imaging an oncogenic disorder associated with expression of CXCR4. For example, such a method can be used on a patient presenting symptoms of an oncogenic disorder. If the patient has, for example increased expression levels of CXCR4, then the patient is likely suffering from a cancerous disorder. As well, the method can be useful for monitoring progression and/or response to treatment in patients who have been previously diagnosed with a CXCR4 mediated cancer. In accordance with the above objective, the invention provides an in vivo imaging reagent comprising an antibody according to the invention, or a functional fragment or derivative thereof, preferably labeled, especially radiolabeled, and its use in medical imaging. Thus, a general method in accordance with the invention works by administering to a patient an imaging-effective amount of an imaging reagent such as the above described monoclonal antibody which is labeled and a pharmaceutically effective carrier and then detecting the agent after it has bound to CXCR4 present in the sample. In certain embodiments, the method works by administering an imaging-effective amount of an imaging agent comprising a targeting moiety and an active moiety. The imaging agent is administered in an amount effective for diagnostic use in a mammal such as a human and the localization and accumulation of the imaging agent is then detected. The localization and accumulation of the imaging agent may be detected by radionucleide imaging, radioscintigraphy, nuclear magnetic resonance imaging, computed tomography, positron emission tomography,

computerized axial tomography, X-ray or magnetic resonance imaging method, fluorescence detection, and chemiluminescent detection.

In regards to the development of targeted antitumor therapy, the diagnosis with immunohistological technics gives in situ information on the receptor expression level and thus enable to select patients susceptible to be treated following the expression level of receptors needed for such a treatment.

For immunotherapy using monoclonal antibodies, the response to the treatment depending of the receptor targeted expression level as treatment with trastuzumab where determination of Her2 overexpression in breast carcinoma is now of major clinical importance with the advent of the humanised anti-Her2 monoclonal antibody trastuzumab. Demonstration of Her2 overexpression is a prerequisite for treatment with trastuzumab as it acts by specifically targeting Her2 overexpressing carcinoma cells. Accurate testing for Her2 aims to ensure that costly and potentially toxic trastuzumab treatment is not given to patients with non-overexpessing tumours and that every patient who might benefit from trastuzumab receives appropriate treatment.

The teaching with trastuzumab concerning the patient selection that overexpressed Her2 showed the benefit to determine the expression level of receptor when using a therapy with a monoclonal antibody and to develop, in the same time than a therapeutic monoclonal antibody, a monoclonal antibody which can be used for the patient selection.

As a consequence, the invention relates to a process of determining in vitro the CXCR4 status of a tumor of a subject, wherein said process comprises the steps of (1) determining the expression level of CXCR4 as above described, (2) scoring said tumor for CXCR4 expression level, and (3) comparing said scoring to that obtained from a control sample.

"CXCR4 status" within the meaning of the invention, relates to the classification of tumor to a CXCR4 positive [CXCR4 (+)] CXCR4 negative [CXCR4 (-)] class based on the determination of the expression level of the CXCR4 gene as measured by any methods such as immunohistochemistry (IHC), fluorescence in situ hybridization (FISH), chromosome in situ hybridization (CISH), gene chip or other methods known by the man skilled in the art.

In a preferred embodiment, the antibody for diagnostic has to be to able to bind the targeted receptor when tissue samples are, formalin fixed, Glyco-fixx fixed, paraffin embedded and/or frozen.

More particularly, the CXCR4 expression level is measured by imunohistochemistry (IHC).

As an example, samples may be scored for CXCR4 expression levels on a scale from 0-3+ for levels of antibody staining, where 0 is negative and 1+-3+ represents positive staining at four semiquantitative steps of increasing intensity. Scores 1+-3+ can be recoded as positive because each positive score may be associated with significantly reduced risk for relapse and fatal disease when compared to score 0 (negative), but increasing intensity among the positive scores may provide additional risk reduction. Any conventional hazard analysis method may be used to estimate the prognostic value of CXCR4. Representative analysis methods include Cox regression analysis, which is a semiparametric method for modeling survival or time-to-event data in the presence of censored cases (Hosmer and Lemeshow, 1999; Cox, 1972). In contrast to other survival analyses, e.g. Life Tables or Kaplan-Meyer, Cox allows the inclusion of predictor variables (covariates) in the models. Using a convention analysis method, e.g., Cox one may be able to test hypotheses regarding the correlation of CXCR4 expression status of in a primary tumor to time-to-onset of either disease relapse (disease-free survival time, or time to metastatic disease), or time to death from the disease (overall survival time). Cox regression analysis is also known as Cox proportional hazard analysis. This method is standard for testing the prognostic value of a tumor marker on patient survival time. When used in multivariate mode, the effect of several covariates are tested in parallel so that individual covariates that have independent prognostic value can be identified, i.e. the most useful markers. The term positive or negative "CXCR4 status" [also referred as CXCR4 (+) or CXCR4 (-)] of tumors refers to scores 0 or scores 1+-3+, respectively.

A sample may be "scored" during the diagnosis or monitoring of breast cancer. In its simplest form, scoring may be categorical negative or positive as judged by visual examination of samples by immunohistochemistry. More quantitative scoring involves judging the two parameters intensity of staining and the proportion of stained ("positive") cells that are sampled. Based on these two parameters numbers may be assigned that reflect increasing levels of positive staining. Allred et al (Allred, Harvey et

al. 1998) have described one way of achieving this, which involved scoring both parameters on a scale from 0 (negative) to 3+, and summarizing the scores of the individual parameters to an overall score. This results in a scale with possible scores of 0, 2, 3, 4, 5, 6, 7 or 8. (Note that a score of 1 is not possible on Allred's scale). A somewhat simpler scoring method integrates the intensity of nuclear staining and the proportion of cells that display stained nuclei into a combined scale from 0 to 3+. Either scoring method may be applied to scoring intensity and proportion of staining of activated Stat5 in the cell nuclei. The terms positive or negative "CXCR4 status" of tumors used in the present description refers to levels of expression of CXCR4 that correspond to scores 0 or 1+-3+ on the simplified scale, respectively.

Generally, the results of a test or assay according to the invention can be presented in any of a variety of formats. The results can be presented in a qualitative fashion. For example, the test report may indicate only whether or not a particular polypeptide was detected, perhaps also with an indication of the limits of detection. The results may be presented in a semi-quantitative fashion. For example, various ranges may be defined, and the ranges may be assigned a score (e.g., 1+ to 3+) that provides a certain degree of quantitative information. Such a score may reflect various factors, e.g., the number of cells in which CXCR4 is detected, the intensity of the signal (which may indicate the level of expression of CXCR4 or CXCR4 bearing cells), etc. The results may be presented in a quantitative fashion, e.g., as a percentage of cells in which the polypeptide (CXCR4) is detected, as a protein concentration, etc. As will be appreciated by one of ordinary skill in the art, the type of output provided by a test will vary depending upon the technical limitations of the test and the biological significance associated with detection of the polypeptide. For example, in the case of certain polypeptides a purely qualitative output (e.g., whether or not the polypeptide is detected at a certain detection level) provides significant information. In other cases a more quantitative output (e.g., a ratio of the level of expression of the polypeptide in the sample being tested versus the normal level) is necessary.

In a more preferred embodiment, scoring of CXCR4 expression level is graded from 0 to 3+, based on an assessment of the intensity of the reaction product and the percentage of positive cells. For more clarity, Table 5 hereinafter summarizes these parameters. Only complete circumferential membranous reactivity of the invasive tumor

should be considered and often resembled a "chicken wire" appearance. Under current guidelines, samples scored as borderline (score of 2+ or more) for CXCR4 IHC must be considered as CXCR4 (+) and are required to undergo further assessment. The IHC analysis should be rejected, and either repeated or tested by FISCH or any other method if, as non limitative example, controls are not as expected, artifacts involve most of the sample and the sample has strong membranous positivity of normal breast ducts (internal controls) suggesting excessive antigen retrieval.

Table 5

CXCR4 status	IHC description
0	No reactivity or membranous reactivity in less than 10% of tumour cells.
1^+	Faint/barely perceptible membranous reactivity is detected in more than 10% of tumour cells. The cells are immunoreactive only in part of the membrane.
2^+	Weak to moderate complete membranous reactivity is seen in more than 10% of tumour cells.
3^+	Strong complete reactivity is seen in more than 10% of tumour cells.

In a more preferred embodiment of the process according to the invention, said scoring comprises using an appropriate scale based on two parameters which are the intensity of the staining and the percentage of positive cells.

In a preferred embodiment, the process according to the invention, refers to an appropriate scale is a scale of 0 to 3+ wherein no membranous reactivity of tumor cells is scored 0, and strong complete reactivity in more than 10% of tumor cells is scored 3+.

In more details, as above described, said appropriate scale is a scale of 0 to 3 wherein no membranous reactivity of tumor cells is scored 0; faint perceptible membranous reactivity in more than 10% of tumor cells is scored 1+; weak to moderate complete membranous reactivity in more than 10% of tumor cells is scored 2+; and strong complete reactivity in more than 10% of tumor cells is scored 3+.

In a particular aspect of the invention, a tumor is CXCR4 (+) with a score of 2+.

In a particular aspect of the invention, a tumor is CXCR4 (+) with a score of 3+.

In another particular aspect of the invention, a tumor is CXCR4 (+) with a score of 2+ or 3+.

According to the invention, it is also described a process of determining whether an oncogenic disorder is susceptible to treatment with a anti-CXCR4 antibody, or a fragment or derivative thereof, wherein said process comprises the steps of (a) determining in vitro the CXCR4 status of a tumor of a subject as above described, and (b) determining that, if the status is CXCR4 (+), the oncogenic disorder is susceptible to treatment with an anti-CXCR4 antibody, or a fragment or derivative thereof.

In another aspect of the invention, it is considered a kit useful for such diagnosing or prognosing process, said kit comprising the antibody of the invention.

As a matter of convenience, a packaged combination of reagents in predetermined amounts with instructions for performing the diagnostic assay, e.g. kits are also within the scope of the invention. The kit contains the antibodies for detection and quantitation of CXCR4 in vitro, e.g. in an ELISA or a Western blot. The antibody of the present invention can be provided in a kit for detection and quantitation of CXCR4 in vitro, e.g. in an ELISA or a Western blot. Where the antibody is labeled with an enzyme, the kit will include substrates and cofactors required by the enzyme (e.g., a substrate precursor which provides the detectable chromophore or fluorophore). In addition, other additives may be included such as stabilizers, buffers (e.g., a block buffer or lysis buffer) and the like. Such a kit may comprise a receptacle being compartmentalized to receive one or more containers such as vials, tubes and the like, such containers holding separate elements of the invention. For example, one container may contain a first antibody bound to an insoluble or partly soluble carrier. A second container may contain soluble, detectably-labeled second antibody, in lyophilized form or in solution. The receptacle may also contain a third container holding a detectably labeled third antibody in lyophilized form or in solution. A kit of this nature can be used in the sandwich assay of the invention. The label or package insert may provide a description of the composition as well as instructions for the intended in vitro or diagnostic use.

The relative amounts of the various reagents may be varied widely to provide for concentrations in solution of the reagents which substantially optimize the sensitivity of the assay. Particularly, the reagents may be provided as dry powders, usually

lyophilized, including excipients which on dissolution will provide a reagent solution having the appropriate concentration.

In yet a further aspect of the invention, monoclonal antibodies or binding fragments thereof as detailed herein are provided labeled with a detectable moiety, such that they may be packaged and used, for example, in kits, to diagnose or identify cells having the aforementioned antigen. Non-limiting examples of such labels include fluorophores such as fluorescein isothiocyanate; chromophores, radionuclides, or enzymes. Such labeled antibodies or binding fragments may be used for the histological localization of the antigen, ELISA, cell sorting, as well as other immunological techniques for detecting or quantifying CXCR4, and cells bearing this antigen, for example.

Kits are also provided that are useful as a positive control for apoptosis assays, for purification or immunoprecipitation of CXCR4 from cells. For isolation and purification of CXCR4, the kit can contain the antibodies described herein or antigen binding fragments thereof coupled to beads (e.g., sepharose beads). Kits can be provided which contain the antibodies for detection and quantitation of CXCR4 in vitro, e.g. in an ELISA or a Western blot. As with the article of manufacture, the kit comprises a container and a label or package insert on or associated with the container. The container holds a composition comprising at least one anti- CXCR4 antibody or binding fragment thereof of the invention. Additional containers may be included that contain, e.g., diluents and buffers, control antibodies. The label or package insert may provide a description of the composition as well as instructions for the intended in vitro or diagnostic use.

More particularly, the invention concerns a kit for the determination of the CXCR4 status of a tumor by any method known by the man skilled in the art. In a preferred embodiment, as it will be described in the example, the invention relates to a kit for the determination of the CXCR4 status of a tumor by IHC methods.

In a particular embodiment, the invention consists in a kit comprising at least an anti-CXCR4 antibody, or a functional fragment or derivative thereof, as above describes, said antibody being preferably labeled.

It must be understood that any labeling method can be used by the man skilled in the art such as, for example, the use of labels above mentioned.

In a preferred embodiment, the kit according to the invention, useful for detecting in vitro the presence and/or the location of a CXCR4 expressing tumor in a subject, further comprises a reagent useful for detecting the extent of binding between the said anti-CXCR4 antibody and CXCR4.

In another preferred embodiment, the kit of the invention useful for determining in vitro the expression level of CXCR4 in a CXCR4 expressing tumor, further comprises a reagent useful for quantifying the level of binding between the said labeled antibody and CXCR4.

In still another embodiment, the kit according to the invention useful for determining in vitro the CXCR4 status of a tumor, further comprises:

i) a reagent useful for detecting the extent of binding between the said labeled antibody and CXCR4; and

ii) positive and negative control samples useful for the scoring the CXCR4 expression level.

Said kit for determining in vitro the CXCR4 status of a tumor can further comprise a polyclonal antibody specific to murine antibodies, preferably said polyclonal antibody specific to murine antibodies is labeled.

The invention also relates to the use of an antibody according to the invention for the preparation of a drug for the specific targeting of a compound that is biologically active toward cells expressing or overexpressing CXCR4.

In the sense of the present description, a "biologically active compound" is any compound capable of modulating, notably inhibiting, cellular activity, notably growth, proliferation, transcription and gene translation.

The invention also relates to an *in vivo* diagnostic reagent composed of an antibody according to the invention, or a functional fragment of same, preferably labeled, notably radiolabeled, and its use in medical imaging, notably for the detection of cancer related to the cellular expression or overexpression of CXCR4.

The invention also relates to a composition as a combination product or to an anti-CXCR4/toxin conjugate or radioisotope, according to the invention, used as drug.

Preferably, said composition as a combination product or said conjugate will be supplemented by an excipient and/or a pharmaceutical vehicle.

In the present description, "pharmaceutical vehicle" means a compound, or a combination of compounds, entering a pharmaceutical composition that does not cause secondary reactions and that, for example, facilitates administration of the active compounds, increases its lifespan and/or effectiveness in the organism, increases its solubility in solution or improves its storage. Such pharmaceutical carriers are well-known and will be adapted by a person skilled in the art according to the nature and the administration route of the active compounds selected.

Preferably, such compounds will be administered by systemic route, notably by intravenous, intramuscular, intradermal, intraperitoneal, subcutaneous or oral route. More preferably, the composition composed of the antibody according to the invention will be administered in several doses spaced equally over time.

Their administration routes, dosing schedules and optimal galenic forms can be determined according to the criteria generally taken into account when establishing a treatment suited to a patient such as, for example, the patient's age or body weight, the seriousness of his general state, his tolerance for the treatment and the side effects experienced.

Thus, the invention relates to the use of an antibody, or one of its functional fragments, for the preparation of a drug for the specific targeting of a compound that is biologically active toward cells expressing or overexpressing CXCR4.

As previously demonstrated, CXCR4 Mabs according to the invention have strong activities in the field of cancer treatment, so such antibodies could be used in screening assays for identification of CXCR4 antagonist anti-tumoral agents to treat cancer. In the first step of these assays, cells expressing CXCR4 are incubated with the antibodies of the invention and then molecules can be evaluated for their potential to inhibit antibodies binding. Cells used in this type of assays can be transfected cell lines such as CHO-CXCR4, NIH3T3-CXCR4 or CXCR4 transfected human cell lines such as U373-MAGI-CXCR4, human cell lines expressing CXCR4 such as NALM6 or primary cells such as PBMC. The method used to screen antagonists of CXCR4 inhibiting antibodies binding on CXCR4 expressing cells can be cell-based competitive enzyme-linked immunosorbent Assay (ELISA) as described by Zhao Q. et al. (AIDS Research And Human Retroviruses, 2003, 19, pp947-955) or protocols using

Fluorescence-Activated cell Sorting (FACS) such as described by Juarez J. et al. (Leukemia 2003, 17, pp1294-1300).

Thus, in a particular aspect of the invention, it is considered a process for the screening and/or the identification of molecules as CXCR4 antagonist anti-tumoral agents comprising the steps of:

a) selecting cells expressing CXCR4,

b) incubating said cells with an antibody, or one of its functional fragments or derivatives, of the invention, and

c) evaluating the tested molecules for their potential inhibition of the binding between the antibody, or one of its functional fragments or derivatives, to CXCR4, and

d) selecting molecules capable of said inhibition.

Other characteristics and advantages of the invention appear further in the description with the examples and figures whose legends are presented below.

FIGURE LEGENDS

Figures 1A and 1B show CXCR4 and CXCR2 expression in cancer cells by qPCR analysis, respectively.

Figure 2 shows CXCR4 and CXCR2 protein expression in cancer cells by FACS analysis.

Figures 3A and 3B show the competition of specific [^{125}I]SDF1 binding by unlabeled SDF-1 (Figure 3A) and 515H7 Mab (Figure 3B) on cellular membranes of CHO-K1 cells stably expressing wild-type human CXCR4 (T: total binding; NS: non-specific binding).

Figure 4 shows the modulation of G protein activation by 515H7 Mab by monitoring [^{35}S]GTPγS binding responses at wild-type CXCR4 receptor stably expressed in NIH-3T3 cells.

Figure 5 shows the modulation of G protein activation by anti-CXCR4 Mab 515H7 by monitoring [^{35}S]GTPγS binding responses at HeLa human tumor cells stimulated with SDF-1 (10 and 100 nM).

Figures 6A-6C show the modulation of CXCR4 receptor association with different interaction partners by SDF-1 and by 515H7 Mab via a bioluminescence resonance energy transfer (BRET) approach in HEK293 cells. (Figure 6A: CXCR4:CXCR4 homo-dimerization; Figure 6B: CXCR2:CXCR4 hetero-dimerization and Figure 6C: CXCR4-mediated recruitment of β-arrestin).

Figures 7A and 7B show the inhibition of forskolin-stimulated cAMP production by SDF-1 and 515H7 Mab in NIH3T3 cells stably expressing CXCR4 receptor.

Figure 8 shows the modulation of G protein activation by anti-CXCR4 Mab 515H7 by monitoring [^{35}S]GTPγS binding responses at constitutively active mutant Asn^{119}Ser CXCR4 receptor stably expressed in CHO-K1 cells.

Figure 9 shows the inhibition of SDF-1-induced U937 cells migration by CXCR4 Mab 515H7 *in vitro*.

Figure 10 shows inhibition of MDA-MB-231 xenograft tumor growth by anti-CXCR4 Mab 515H7 in Nod/Scid mice.

Figures 11A-11C show the SDF-1-induced calcium release inhibition by anti-CXCR4 Mab 515H7 in CHO-CXCR4 cells (Figure 11A) and MDA-MB-231 (Figure 11B), U937 (Figure 11C) cancer cells.

Figure 12 shows the activity of murine anti-CXCR4 Mab m515H7 in U937 Nod/Scid mice survival model.

Figure 13 shows the activity of murine anti-CXCR4 Mab m515H7 in inhibition of T-cell KARPAS 299 xenograft tumor growth in Nod/Scid mice.

Figure 14 shows the competition of specific [^{125}I]SDF1 binding by murine m515H7 Mab and chimeric c515H7 Mab on cellular membranes of CHO-K1 cells stably expressing wild-type human CXCR4 (T: total binding; NS: non-specific binding).

Figure 15 shows the modulation of G protein activation by murine m515H7 Mab and by chimeric c515H7 Mab by monitoring [^{35}S]GTPγS binding responses at wild-type CXCR4 receptor stably expressed in NIH-3T3 cells stimulated with SDF-1 (10 nM).

Figure 16 shows the modulation of G protein activation by anti-CXCR4 murine m515H7 Mab and chimeric c515H7 Mab by monitoring [^{35}S]GTPγS binding responses at HeLa human tumor cells stimulated with SDF-1 (10 nM).

Figures 17A-17C show the modulation of CXCR4 receptor association with different interaction partners by SDF-1 and by m515H7 and c515H7 Mabs via a bioluminescence resonance energy transfer (BRET) approach in HEK293 cells. (Figure 17A: CXCR4:CXCR4 homo-dimerization; Figure 17B: CXCR2:CXCR4 hetero-dimerization and Figures 17C: CXCR4-mediated recruitment of β-arrestin).

Figures 18A and 18B show the inhibition of SDF-1-induced calcium release in CHO-CXCR4 cells (figure 18A) and in U937 cells (Figure 18B).

Figure 19 shows the inhibition of SDF-1-induced U937 cells migration by anti-CXCR4 Mabs m515H7 and c515H7 *in vitro*.

Figure 20 shows the anti-CXCR4 chimeric Mab c515H7 activity in U937 Nod/Scid mice survival model.

Figure 21 shows the amino acid sequences alignment of 515H7 heavy chain variable domain with the human germline IGHV3-49*04 and IGHJ4*01. The 515H7 VH amino acid sequence is aligned with the selected human acceptor framework sequences. VH1 and VH2 (VH3 is not represented) sequences correspond to implemented humanized variants of the 515H7 VH domain, with back mutated residues in bold. Variant 1 VH1 carries no back mutated residue and represents a fully human variant. Variant VH2 has 8 back mutations and is the most murine variant. Variant VH3 carry 5 back mutations (not represented).

Figure 22 shows the amino acid sequences alignment of 515H7 light chain with the human germline IGKV4-1*01 and IGKJ1*01. The 515H7 VL amino acid sequence is aligned with the selected human acceptor framework sequences. VL1 to VL3 sequences correspond to implemented humanized variants of the 515H7 VL domain, with back mutated residues in bold. Variant VL1 carries no back mutated residue and represents the most human variant. Variant VL2 has 13 back mutations and is the most murine variant. Variant VL3 carry 5 back mutations.

Figures 23A-23F show cross blocking of the biotinylated murine antibody 515H7 by the chimeric 515H7 and different variants of the humanized 515H7. The activity of the humanized variants of 515H7 (hz515H7) to cross block the parental murine antibody 515H7 was evaluated by flow cytometry using CXCR4 transfected NIH3T3 cells. The activity of the humanized variants was compared to the chimeric 515H7. The cross blocking activity of the three different variants of VH (VH1 - VH3)

combined with the chimeric VL (cVL) were very similar (Figure 23A – Figure 23C). No reduction in the activity of VH variant 1 (VH1, the variant with no back mutations) was determined when combined with variant 1 and 2 of VL. A significant reduction of the activity was detected for the construct hz515H7 VH1 VL3.

Figure 24 shows the BRET assay for testing the activity of the humanized antibody 515H7 variant VH1 VL1. The activity of the humanized variant 515H7 VH variant 1 VL variant 1 (hz515H7 VH1 VL1) was evaluated by its capacity to inhibit SDF-1 mediated signal transduction. This variant showed only a minor inhibition of the SDF-1 mediated signal transduction as determined by BRET. SDF-1 was used at a concentration of 100nM.

Figures 25A-25D show comparison of different mutants of the VH1 with single or double back mutations and combinations of different VL variants with hz515H7 VH1 D76N. Single and double back mutations were made in the VH1 and combined with the VL1. These constructs were evaluated in BRET assays (Figures 25A-25C). Of these single back mutants only the construct with the back mutation D76N showed an increased inhibition of the SDF-1 mediated signal transduction. None of the double back mutant in VH had strong inhibitory activity (Figure 25C). The single back mutant D76N of the VH1 was combined with different variants of VL. The SDF-1 concentration was 100nM.

Figure 26 shows ranking of different mutants of the VH1 and VL1 with single or double back mutations in comparison to the construct VH1 D76N VL2. Single and double back mutations were made in the VH1 and combined with the VL1. All constructs were evaluated in BRET assays and their percent inhibition calculated. The SDF-1 concentration was 100nM.

Figures 27A-27B show inhibition of SDF-1 binding by different constructs of the humanized 515H7 and correlation between result obtained by FACS and BRET. The different variants of the humanized antibody 515H7 with a strong activity in blocking the recruitment of β-arrestin were tested in their capacity to inhibit the binding of biotinylated SDF-1 in flow cytometry (FACS) (A). These were compared with VH1 and VL1. Results from the FACS-based assay are correlated with the results obtained by BRET (B).

Figure 28 shows the amino acid sequences alignment of hz515H7 VL2 and further humanized versions 515H7 VL2.1, 515H7 VL2.2 and 515H7 VL2.3. The 515H7 VL amino acid sequence is aligned with the selected human acceptor framework sequences. VL2.1, VL2.2 and VL2.3 sequences correspond to implemented humanized variants of the humanized 515H7 VL2, with mutated residues in bold. VL2.1 and VL2.2 carry 4 more humanized residues whereas VL2.3 contains 5 more human residues.

Figures 29A-29C show the 515H7 humanized Mabs (hz515H7 VH1 D76N VL2, hz515H7 VH1 D76N VL2.1, hz515H7 VH1 D76N VL2.2 and hz515H7 VH1 D76N VL2.3) specific binding to CXCR4 on NIH3T3-CXCR4 (Figure 29A) U937 (Figure 29B) and Ramos cells (Figure 29C).

Figures 30A-30D and 31 show the modulation of G protein activation by humanized Mabs 515H7 (hz515H7 VH1 D76N VL2 [Fig. 30A], hz515H7 VH1 D76N VL2.1 [Fig. 30B], hz515H7 VH1 D76N VL2.2 [Fig. 30C] and hz515H7 VH1 D76N VL2.3 [Fig. 30D]) by monitoring [^{35}S]GTPγS binding responses at wild-type CXCR4 receptor stably expressed in NIH-3T3 cells stimulated with SDF-1 (10 nM or 100 nM).

Figures 32A-32C show the modulation of CXCR4 receptor association with different interaction partners by SDF-1 and by humanized 515H7 Mabs (hz515H7 VH1 D76N VL2, hz515H7 VH1 D76N VL2.1, hz515H7 VH1 D76N VL2.2 and hz515H7 VH1 D76N VL2.3) via a bioluminescence resonance energy transfer (BRET) approach in HEK293 cells. (Figure 32A: CXCR4:CXCR4 homo-dimerization; Figure 32B: CXCR2:CXCR4 hetero-dimerization and Figure 32C: CXCR4-mediated recruitment of β-arrestin).

Figures 33A-33D illustrate RAMOS and KARPAS299 xenograft tumors Glyofixx-fixed with a) and c) IHC staining using 515H7 / b) and d) IHC staining using mIgG1.

Figures 34A-34D illustrate RAMOS and KARPAS299 xenograft tumors Formol-fixed with a) and c) IHC staining using 515H7 / b) and d) IHC staining using mIgG1.

Figures 35A-35D show the competition of specific [^{125}I]SDF1 binding by humanized hz515H7 Mabs (hz515H7 VH1 D76N VL2 [Figs. 35A & B], hz515H7 VH1 D76N VL2.1 [Figs. 35A & 35C], hz515H7 VH1 D76N VL2.2 [Figs. 35A & 35D], hz

515H7 VH1 D76N VL2.3 [Fig. 35A]) on cellular membranes of CHO-K1 cells stably expressing wild-type human CXCR4 (T: total binding ; NS: non-specific binding).

Figure 36 shows the inhibition of SDF-1-induced calcium release in U937 cells by hz515H7 VH1 D76N VL2 Mab.

Figures 37A-37B show the inhibition of SDF-1-induced U937 cells migration by CXCR4 humanized Mab hz515H7 VH1 D76N VL2 *in vitro*.

Figure 38: RAMOS and KARPAS299 xenograft tumors Glyofixx-fixed with a) and c) IHC staining using biotinylated hz515H7 VH1 D76N VL2 and b) and d) IHC staining using biotinylated hIgG1

Figure 39: RAMOS and KARPAS299 xenograft tumors Formol-fixed with a) and c) IHC staining biotinylated hz515H7 VH1 D76N VL2 and b) and d) IHC staining biotinylated hIgG1.Figure 40 shows the effect of chimeric 515H7 (c515H7) Mab on B-cell Ramos xenograft tumor growth in Scid mice.

Figure 41 shows the effect of version hz515H7 VH1 D76N VL2 Mab on B-cell Ramos xenograft tumor growth in Scid mice.

Figure 42 shows the effect of version hz515H7 VH1 D76N VL2.1 Mab on B-cell Ramos xenograft tumor growth in Scid mice.

EXAMPLES

Example 1: Expression of CXCR4 and CXCR2 in cancer cells

- Q-PCR analysis:

In order to quantify the relative expression of CXCR4 and CXCR2 in different cancer cell lines, a real time RT-PCR was used.

RNA samples were extracted from different cell lines using RNeasy Mini or Midi Protocols (Qiagen Corporation, France). The RNA samples were then controlled using the Experion automated electrophoresis system (BIO-RAD Corporation, France) and showed a good quality/integrity. One µg of each RNA sample was converted into cDNA template using the iScript cDNA Synthesis kit (BIO-RAD Corporation, France). cDNA levels were quantified using qPCR with either a TaqMan probe for CXCR2 or SYBERGreen for CXCR4. Comparing samples requires normalization, so was

introduced the internal reference RPL0. TaqMan probes (used for CXCR2) carried a 5' FAM reporter label and a 3' TAMRA quencher group. The PCR enzyme was activated by heating for 2 min at 50°C and 10 min at 95°C. A two step procedure was used, 15 sec at 95°C and 1 min at 62°C for 40 or 45 cycles in a PCR mix containing 5 µl of cDNA template (dilution 1/20), 1 x qPCR Mastermix (TaqMan Universal PCR Master Mix, Applied Biosystems corporation, Branchburg New Jersey, USA), 50 to 900 nM of each primers and 50 to 100 nM probe in a total volume of 50 µl. All reactions were performed using iCycler instrument (BIO-RAD Corporation). Q-PCR allowed to determine Cycle threshold (Ct). The more the Ct value is small, the more the gene tested is expressed. Primers and probe for Human Ribosomal protein, large, P0 were:

forward primer, 5'-GAAACTCTGCATTCTCGCTTCCTG-3' (SEQ ID No.63);

reverse primer, 5'-AGGACTCGTTTGTACCCGTTGA-3'(SEQ ID No.64);

probe, 5 -(FAM)- TGCAGATTGGCTACCCAACTGTTGCA-(TAMRA)-3' (SEQ ID No. 65).

Primers for Human CXCR4 (chemokine receptor 4) were:

forward primer, 5'-CTCCTTCATCCTCCTGGAAATC-3' (SEQ ID No. 66);

reverse primer, 5'-CCAAGGAAAGCATAGAGGATGG-3' (SEQ ID No. 67).

Primers and probe for Human CXCR2 (chemokine receptor 2) were:

forward primer, 5'-GTGGTCATTATCTATGCCCTGG-3' (SEQ ID No. 68);

reverse primer, 5'-CGACCCTGCTGTATAAGATGAC-3' (SEQ ID No.69);

probe, 5 -(FAM)- TATTCCTGCTGAGCCTGCTGGGAAA-(TAMRA)-3' (SEQ ID No. 70).

In our comparative study, the expression of two genes [the gene tested (CXCR4 or CXCR2) and RPL0]) were quantified in two different samples: the cell line tested and a reference cell line. The reference cell line corresponded to the cell line containing the lowest expression of the gene quantified. Comparative gene expression calculation was made using the following formula:

Relative gene expression = $(1+E_{gene})^{-\Delta Ct(1)} / (1+E_{RPL0})^{-\Delta Ct(2)}$

E_{gene} = PCR efficiency using primers/probe of the gene quantified

E_{RPL0} = PCR efficiency using the RPL0 primers/probe

Ct = threshold cycle

$\Delta Ct(1) = Ct_{gene}$ (cell line tested) - Ct_{gene} (reference cell line)

$\Delta Ct(2) = Ct_{RPLO}$ (cell line tested) - Ct_{RPLO} (reference cell line)

For each PCR series, a relative gene quantity value was calculated, and cancer cell lines were classified into groups considering their levels of expression from the highest to negative. All data are presented in Figures 1A and 1B. All the cancer cell lines tested expressed CXCR4 (Figure 1A) and CXCR2 excepted DU145 and U-87MG for CXCR2 (Figure 1B).

- *FACS analysis:*

MDA-MB-231, PC3 and U937 cancer cell lines were permebilized and then incubated with either 10 µg/mL of anti-CXCR4 monoclonal antibodies [44717 (R&D Systems) versus its isotype control IgG2b (SIGMA] or 10 µg/mL of anti-CXCR2 monoclonal antibodies (anti h-CXCR2, clone 48311, R&D Systems, Mab 331 versus its isotype control IgG2a). The cells were then washed with 1%BSA/PBS/0.01% NaN3. Next, Alexa-labeled secondary antibodies were added to the cells and were allowed to incubate at 4°C for 20 min. Cells were then washed again two times. Following the second wash, FACS analysis was performed. Results of these binding studies are provided in Figure 2. Thus, tumor cells such as MDA-MB-231, PC3 and U937 expressed both CXCR4 and CXCR2 proteins.

Example 2: Generation of monoclonal antibodies (Mabs) against human CXCR4

To generate monoclonal antibodies to CXCR4, Balb/c mice were immunized with recombinant NIH3T3-CXCR4 cells and/or peptides corresponding to CXCR4 extracellular N-term and loops. The mice 6-16 weeks of age upon the first immunization, were immunized once with the antigen in complete Freund's adjuvant subcutaneously (s.c.) followed by 2 to 6 immunizations with antigen in incomplete Freund's adjuvant s.c. The immune response was monitored by retroorbital bleeds. The serum was screened by ELISA (as described bellow) and mice with the higher titers of anti-CXCR4 antibodies were used for fusions. Mice were boost intravenously with antigen two days before sacrifice and removal of the spleen.

- *ELISA*

To select the mice producing anti-CXCR4 antibodies, sera from immunized mice was tested by ELISA. Briefly, microtiter plates were coated with purified [1-41] N-terminal peptide conjugated to BSA at 5µg equivalent peptide/mL, 100µL/well incubated at 4°C overnight, then blocked with 250µL/well of 0.5% gelatine in PBS. Dilutions of plasma from CXCR4-immunized mice were added to each well and incubated 2 hours at 37°C. The plates were washed with PBS and then incubated with a goat anti-mouse IgG antibody conjugated to HRP (Jackson Laboratories) for 1 hour at 37°C. After washing, plates were developed with TMB substrate, the reaction was stopped 5 min later by addition of 100 µL/well 1M H_2SO_4. Mice that developed the highest titers of anti-CXCR4 antibodies were used for antibody generation.

- Generation of hybridomas producing Mabs to CXCR4

The mouse splenocytes, isolated from a Balb/c mice that developed the highest titers of anti-CXCR4 antibodies were fused with PEG to a mouse myeloma cell line Sp2/O. Cells were plated at approximately 1x 10^5 /well in microtiter plates followed by two weeks incubation in selective medium containing ultra culture medium + 2 mM L-glutamine + 1 mM sodium pyruvate + 1x HAT. Wells were then screened by ELISA for anti-CXCR4 monoclonal IgG antibodies. The antibody secreting hybridomas were then subcloned at least twice by limiting dilution, cultured *in vitro* to generate antibody for further analysis.

Example 3: Characterization by FACS analysis of anti-CXCR4 Mab 515H7 binding specificity and cancer cell lines recognition

In this experiment, specific binding to human CXCR4 of anti-CXCR4 Mab 515H7 was examined by FACS analysis.

NIH3T3, NIH3T3-hCXCR4 transfected cells, MDA-MB-231, Hela and U937 cancer cell lines were incubated with 10 µg/mL of monoclonal antibody 515H7. The cells were then washed with 1%BSA/PBS/0.01% NaN3. Next, Alexa-labeled secondary antibodies were added to the cells and were allowed to incubate at 4°C for 20 min. The cells were then washed again two times. Following the second wash, FACS analysis was performed. Results of these binding studies are provided in the following Table 6 which shows [Mean Fluorescence Intensity (MFI) obtained by FACS] that anti-CXCR4 Mab 515H7 bound specifically to human CXCR4-NIH3T3 transfected cell line whereas

there was no recognition on the parent NIH3T3 cells. This Mab was also able to recognize human cancer cell lines, for examples MDA-MB-231 breast cancer cells, U937 promyelocytic cancer cells and Hela cervix cancer cells.

Anti-CXCR4 Mab 515H7 recognized NIH3T3-hCXCR4 transfectant while there was no recognition of the parent NIH3T3 wild type cells. Mab 515H7 was also able to recognize cancer cell lines.

Table 6

Clone	MFI on cell lines				
(10 µg/ml)	NIH3T3	NIH3T3-CXCR4	MDA-MB-231	Hela	U937
515H7	16	2752	239	1851	645

Example 4: Competition binding of anti-CXCR4 Mab 515H7 for [^{125}I]SDF-1 at CHO-K1 membranes stably expressing human CXCR4 receptor

This assay allows to evaluate the ability of 515H7 Mab to compete for binding of radio labeled [^{125}I]SDF-1 to human CXCR4 receptor, at either orthosteric or allosteric binding sites.

CHO-K1 cells, stably and constitutively expressing human CXCR4 receptor were obtained upon transfection of naïve CHO-K1 cells (ATCC CCL-61) with a mammalian expression vector carrying the whole coding sequence of human CXCR4 receptor (RefSeq NM_003467). Cells were propagated in complete culture medium [DMEM-Ham's F12 supplemented with 5 % fetal calf serum (FCS) and 500 µg/ml of geneticin]. Radioligand binding experiments were conducted on cell membranes obtained upon mechanical scrapping of CHO/CXCR4 cells in lysis buffer [Hepes 20mM, pH 7.4, NaCl 150mM] followed by centrifugation (10000g, 15 min). [^{125}I]SDF-1 binding (specific activity: 1500 Ci/mmol) was performed using the SPA technology (scintillation proximity assay – GE Healthcare). Briefly, cell membranes (30 µg/well) were incubated in binding buffer [Hepes 20mM, pH 7.4, $CaCl_2$ 1mM, $MgCl_2$ 5mM, NaCl 150mM, BSA 1%] together with compound to evaluate (SDF-1 or mAb), radioligand (1 nM) and finally SPA-WGA-PVT beads (7.3 mg/well). Binding equilibrium was reach after 1H at 25 °C. Upon centrifugation [1000 g for 10 min.]

radioactive counts were measured in a scintillation counter (TopCount, Perkin Elmer). Non-specific binding was estimated in the presence of 10 µM of unlabelled SDF-1.

Unlabelled SDF-1 dose-dependently inhibited [^{125}I]SDF-1 binding with a pKi value (IC_{50} = ligand concentration yielding 50 % inhibition of specific [^{125}I]SDF-1 binding) of 7.75 ± 0.27 nM (n=4) (Figure 3A). Under the same experimental conditions, 515H7 (100 nM) efficiently competed for [^{125}I]SDF-1 binding (% inhibition of [^{125}I]SDF-1): (64±3%) (Figure 3B).

Example 5: Modulation of [^{35}S]GTPγS binding at cellular membranes expressing wild type CXCR4 receptor by anti-CXCR4 Mab 515H7

This functional assay allows to monitor G protein activation via wild type human CXCR4 receptor and its modulation by CXCR4 ligands and 515H7 Mab.

NIH-3T3 cells stably and constitutively expressing wild-type CXCR4 receptor were obtained as described in the example above for CHO-K1 cells. HeLa (human cervix carcinoma) cells were propagated in complete culture medium [EMEM supplemented with 10% FCS, 1% L-glutamine, 2 µ sodium bicarbonate]. [^{35}S]GTPγS binding was performed on cellular membranes obtained upon mechanical scrapping in lysis buffer [Hepes 20mM, pH 7.4, NaCl 150mM] and further centrifugation (10000 g, 15 min). Incorporation and detection of [^{35}S]GTPγS (specific activity: 1000 Ci/mmol) was performed using the SPA technology (scintillation proximity assay - GE Healthcare). Briefly, cell membranes (10 µg/well) were incubated in binding buffer [Hepes 20mM, GDP 3µM, $MgCl_2$ 10mM, NaCl 100mM, EDTA 1mM, pH=7.4] together with compound to evaluate (SDF-1 or Mab of interest), [^{35}S]GTPγS (0.2-0.4 nM) and finally SPA-WGA-PVT beads (7.3 mg/well). Binding reaction was performed during 1H at 25°C. Upon centrifugation [1000 g for 10 min.] radioactive counts were measured in a scintillation counter (TopCount, Perkin Elmer). Antagonist potency was calculated by applying the Cheng Prussof equation:

K_B= [conc antago]/{(EC_{50}'/EC_{50})-1} where EC_{50} and EC_{50}' are respectively the potency of SDF-1 in the absence and presence of mAb.

SDF-1 induced a dose-dependent increase of [^{35}S]GTPγS binding, as the result of G protein activation by CXCR4 receptor. Maximal stimulation of [^{35}S]GTPγS binding represents respectively 167 % and 320 % over basal [^{35}S]GTPγS binding for

HeLa and NIH3T3/CXCR4 cell membranes. The potency of SDF-1 was similar for both cell lines and corresponded to 41.3 ± 9.7 nM (Figure 4). Under these experimental conditions, the antagonist potency of 515H7 Mab, as determined in NIH3T3/CXCR4 cells was 15 nM. Similar antagonist efficacy was observed for HeLa cells (Figure 5).

Example 6: Association of CXCR4 with different interaction partners: homo and heterodimerization, recruitment of β-arrestin via a bioluminescence resonance energy transfer (BRET) approach and effect of 515H7 Mab on these dimers

This functional assay allows to evaluate the conformational changes induced upon SDF-1 and/or 515H7 Mab binding to CXCR4 receptor at the level of CXCR4 homo-dimer and CXCR2/CXCR4 hetero-dimer formation as well as the recruitment of the β-arrestin-2 signaling protein.

Expression vectors for each of the investigated interaction partners were constructed as fusion proteins with the corresponding dye (*Renilla reniformis* luciferase, Rluc and Yellow fluorescent protein, YFP) by applying conventional molecular biology techniques. Two days prior performing BRET experiments, HEK293 cells were transiently transfected with expression vectors coding for the corresponding BRET partners: [CXCR4/Rluc + CXCR4/YFP] to study CXCR4 homo dimerization, [CXCR4/Rluc + CXCR2:YFP] to study CXCR4 and CXCR2 hetero-dimerization and [CXCR4/Rluc + β-arr2:YFP] to study CXCR4-mediated recruitment of β-arrestin-2. The day after, cells were distributed in poly-lysine pre-coated white 96 MW plates in complete culture medium [DMEM supplemented with 10 % FBS]. Cells were first cultivated at 37°C with CO_2 5 % in order to allow cell attachment to the plate. Cells were then starved with 200 µl DMEM/well overnight. Immediately prior to the BRET experiment, DMEM was removed and cells were quickly washed with PBS. Cells were then incubated in PBS in the presence or absence of antibody, 10 min at 37°C prior to the addition of coelenterazine H 5 µM with or without SDF-1 300 nM in a final volume of 50 µl. After incubation for further 10 minutes at 37°C, light-emission acquisition at 485 nm and 530 nm was initiated using the Mithras LB940 multilabel reader (Berthold) (1s/wavelength/well repeated 15 times at room temperature).

Calculation of BRET ratio was performed as previously described (Angers et al., 2000): [(emission$_{530\ nm}$) - (emission$_{485\ nm}$) X Cf] / (emission$_{485\ nm}$), where Cf = (emission$_{530\ nm}$) / (emission$_{485\ nm}$) for cells expressing the Rluc fusion protein alone under the same experimental conditions. Simplifying this equation shows that BRET ratio corresponds to the ratio 530/485 nm obtained when the two BRET partners are present, corrected by the ratio 530/485 nm obtained under the same experimental conditions, when only the partner fused to Rluc is present in the assay. For sake of readability, results are expressed in milliBRET units (mBU); mBU corresponds to the BRET ratio multiplied by 1000.

SDF1 (300 nM) increased by about 20 % the BRET signal resulting from the spatial proximity of the adaptor and acceptor proteins fused to CXCR4 receptor, it is likely to indicate CXCR4/CXCR4 homo-dimers formation or conformational changes of pre-existing dimers (Figure 6A). Interestingly, SDF1 (300 nM) decreased by about 24 % the BRET signal resulting from the spatial proximity of the adaptor and acceptor proteins fused to CXCR2 and CXCR4, likely indicating as well CXCR2/CXCR4 hetero-dimers formation or conformational changes of pre-existing dimers (Figure 6B). In this latter case, SDF-1-activated conformation of CXCR4/CXCR2 seems less favorable for BRET energy transfer. In both cases, 515H7 Mab was able to modulate SDF-1-induced conformational changes for CXCR4 homo-dimers (69 % inhibition of SDF-1-induced BRET increase, Figure 6A) as well as for CXCR2/CXCR4 hetero-dimer formation (90 % inhibition of SDF-1-induced BRET decrease for 515H7, Figure 6B). 515H7 Mab was also able to modulate by itself CXCR4/CXCR4 and CXCR2/CXCR4 spatial proximity respectively, indicating an influence of 515H7 Mab on both CXCR4/CXCR4 homo and CXCR2/CXCR4 hetero-dimer conformation (Figures 6A and 6B).

CXCR4 activation by SDF-1 (300 nM) yielded a strong recruitment of the intracellular signaling molecule β-arrestin, as shown by the 233 % enhancement in BRET signal (Figure 6C). This recruitment was partially inhibited by 515H7 Mab (about 95 %, Figure 6C) showing the effect of Mab 515H7 on signaling.

Example 7: CXCR4-mediated inhibition of cAMP production

This functional assay was designed to monitor CXCR4 receptor signaling at the level of adenylate cyclases via inhibitory Gi/o proteins.

The cAMP LANCE procedure (Perkin Elmer) was applied as detailed by the supplier. Briefly, NIH3T3 cells stably and constitutively expressing wild type CXCR4 receptor were obtained and propagated as described above. Cells were collected using the trypsin-free agent Versene and resuspended at a concentration of 10^6 cells/ml in a solution containing the AlexaFluor-bound anti cAMP Mab ($1/100^{th}$ dilution) and compound (forskolin, SDF-1 and/or 515H7 Mab). Upon incubation for 30 min. at room temperature, the detection mix containing the Europium-Streptavidin ($1/125^{th}$ dilution) and Biotin-cAMP ($1/125^{th}$ dilution) complexes was added. Upon incubation for 1 hour at room temperature, the resulting FRET signal was measured in a Mithras LB940 (Berthold) multilabel reader. Data are expressed either as arbitrary fluorescent values or as a relative stimulation versus SDF-1 response upon substraction of the FK effect.

Forskolin (FK) dose-dependently stimulated cAMP production with a potency of about 0.3 µM in NIH3T3/CXCR4 cells (Figure 7A). In the co-presence of SDF-1, intracellular cAMP levels decreased as a result of inhibitory Gi/o protein activation by CXCR4 receptor. The potency of SDF-1 was 5.0 ± 3.1 nM (Figure 7A). 515H7 Mab efficiently inhibited the forskolin-stimulated effect of SDF-1 (100 nM) by more than 80 % (Figure 7B).

Example 8: Modulation of [^{35}S]GTPγS binding at cellular membranes expressing constitutively active mutant Asn^{119}Ser CXCR4 receptor by Mab 515H7

This functional assay allows to monitor G protein activation via a constitutively active mutant (CAM) Asn^{119}Ser CXCR4 receptor (see Zhang et al., 2002). This sensitive assay allows to discriminate CXCR4 ligands based on their intrinsic activity (partial agonist, silent antagonist or inverse agonist). As previously described by Zhang and colleagues, CXCR4 ligands such as AMD3100 or T140 behaved respectively as partial agonist and inverse agonist at CAM CXCR4 receptor. Identification of silent antagonist may be difficult since this class of molecule must display similar affinities for both active and inactive states of CXCR4 (Wurch et al., 1999).

Introduction of an Asn119Ser mutation in the coding sequence of CXCR4 receptor was performed by applying conventional molecular biology techniques

(QuickChange site directed mutagenesis kit, Stratagene US). CHO-K1 cells stably and constitutively expressing CAM CXCR4 receptor were obtained as described in the example above. [^{35}S]GTPγS binding was performed on cellular membranes obtained upon mechanical scrapping in lysis buffer [Hepes 20mM, pH 7.4, NaCl 150mM] and further centrifugation (10000 g, 15 min). Incorporation of [^{35}S]GTPγS (specific activity: 1000 Ci/mmol) was performed using the SPA technology (scintillation proximity assay – GE Healthcare). Briefly, cell membranes (10 µg/well) were incubated in binding buffer [Hepes 20mM, GDP 3µM, $MgCl_2$ 10mM, NaCl 100mM, EDTA 1mM, pH=7.4] together with compound to evaluate (SDF-1 or mAb), [^{35}S]GTPγS (0.2-0.4 nM) and finally SPA-WGA-PVT beads (7.3 mg/well). Binding reaction was performed during 1H at 25°C. Upon centrifugation [1000 g for 10 min.] radioactive counts were measured in a scintillation counter (TopCount, Perkin Elmer).

SDF-1 (100 nM) stimulated [^{35}S]GTPγS binding by 130 %. The inverse agonist T140 inhibited both basal (- 17 %) and SDF-1-stimulated (- 159 %) [^{35}S]GTPγS binding. In contrast, 515H7 Mab behaved as silent antagonists at CAM CXCR4, without altering basal [^{35}S]GTPγS binding (Figure 8) but inhibiting SDF-1 induced [^{35}S]GTPγS binding (Figure 8).

Example 9: Effect of anti-CXCR4 Mab 515H7 on SDF-1-induced U937 cells migration

To evaluate the inhibiting effect of the anti-CXCR4 monoclonal antibody 515H7 on the migration process, 100 000 U-937 cells in RPMI 1640 medium supplemented with 2% FCS, were plated in the upper chamber of migration chambers (24 wells plates with 8-µm pore size) either in presence or in absence of SDF-1 in the lower part of the wells and with or without Mab 515H7 in the upper chamber. In this test murine IgG2b was introduced as an isotype control. Two hours after plating, migrating cells were counted. The results presented in figure 9 demonstrated that, as expected SDF-1 was able to induce a significant increase of U-937 cells migration. No effect was observed when cells were incubated with the IgG2b isotype control. In contrast, for cells incubated with the 515H7 Mab, a significant and reproducible decrease in SDF-1-induced U937 cells migration was observed: more than 80%.

Example 10: Anti-CXCR4 Mab 515H7 inhibition of MDA-MB-231 xenograft tumor growth in Nod/Scid mice

The goal of these experiments was to evaluate the ability of anti-CXCR4 Mab 515H7 to inhibit the growth of MDB-MB-231 xenograft in Nod/SCID mice.

MDA-MB-231 cells from ECACC were routinely cultured in DMEM medium (Invitrogen Corporation, Scotland, UK), 10% FCS (Sigma, St Louis MD, USA). Cells were split 48 hours before engraftment so that they were in exponential phase of growth. Ten million MDA-MB-231 cells were engrafted in PBS to 7 weeks old Nod/Scid mice (Charles River, France). Five days after implantation, tumors were measurable (34 mm^3<V^3<40 mm^3) and animals were divided into groups of 6 mice with comparable tumor size. Mice were treated i.p. with a 2 mg/mouse loading dose of Mab 515H7.

Then, mice were injected twice a week at 0.5 mg/dose/mouse of Mab 515H7 three time a week. A PBS group was introduced as a control group in this experiment. Tumor volume was measured twice a week and calculated by the formula: $\pi/6$ X length X width X height. Statistical analysis were performed at each measure using a Mann-Whitney test.

In these experiments, no mortality was observed during treatment. Compared to PBS group, there was a significant inhibition of tumor growth between D7 and D39 ($p \leq 0.002$) for 515H7 0.5mg/dose and the average tumor volume after 5 weeks of treatment was reduced by 50% versus PBS for Mab 515H7 (Figure 10).

Example 11: CXCR4 receptor-mediated mobilization of intracellular calcium stores

This functional assay was designed to monitor CXCR4 receptor signaling via stimulation of the phospholipase C pathway, inducing calcium liberation from intracellular stores from the endoplasmic reticulum.

CHO-K1 cells stably and constitutively expressing wild-type CXCR4 receptor were obtained as described in the example above. MDA-MB-231 (human breast adenocarcinoma) and U937 (human leukemia) cells were propagated in complete culture medium, respectively [DMEM supplemented with 10% FCS] and [RPMI 1640 supplemented with 10% FCS, 20 mM HEPES, 1% non-essential amino acid solution,

1% sodium pyruvate, 1% L-glutamine, 4.5 g/l glucose]. All cell types were plated in black 96MW plates at a density of 100,000 cells/well in appropriate culture medium. Cells were starved overnight before conducting the experiments. Cells were loaded with the fluorescent calcium dye (Fluo-4 No Wash, Invitrogen US) in loading buffer [HBSS 1x, HEPES 20 mM, Probenicid acid 25 mM] for 30 min. at 37 °C followed by 30 min. at 25°C. Stimulation by SDF-1 was performed by direct injection into each well. For antagonism experiments, 10 µl of Mab solution were added directly into the loading buffer at least 10 min. before SDF-1. Kinetic fluorescence measurements were performed on a multi-mode fluorescence microplate reader Mithras LB940 (Berthold) using the following settings: excitation at 485 nm, emission at 535 nm, excitation energy at 10000 arbitrary units. Fluorescence in each well was recorded during 0,1 second every second and for a time period of 20 sec prior SDF-1 injection (basal signal). Then 20 µl of SDF-1 were injected and data recording followed for a time period of 2 min. Each experimental condition was performed in duplicate. Values for each well are first corrected by substracting the basal fluorescence and the fluorescence emitted by a control well without cells. Relative data were expressed as a percentage of the maximal stimulation obtained by SDF-1 (100 nM).

SDF1 (100 nM) induced a rapid and strong release of intracellular calcium in recombinant CHO/CXCR4, whereas no fluorescence signal was detected in naïve CHO-K1 cells. The maximal intensity reached > 160 % over basal fluorescence and was observed at about 30 sec. upon stimulation by SDF-1; similar kinetic curves were observed with both MDA-MB-231 and U-937 (Figures 11A, 11B, 11C), although the maximal fluorescence intensity by SDF-1 (100 nM) was lower (130-140 % over basal). 515H7 antibody (133 nM) yielded a strong and almost complete inhibition of the SDF-1 (100 nM)-induced calcium signal in all three investigated cell lines.

Example 12: Anti-CXCR4 Mab 515H7 activity in U937 mice survival model

U937 cells from ATCC were cultured in RPMI 1640 medium, 10% FCS, 1% L-Glutamine. Cells were split two days before engraftment so that they were in exponential phase of growth. Ten million U937 cells injected i.p. to female NOD/SCID mice. Two days after implantation, mice were treated s.c. with a loading dose of 2 mg of 515H7 Mab/mouse and then twice a week with 1 mg of antibody/mouse. Control mice

received PBS injections as it has been shown in previous studies that no difference in survival was observed between mice injected with PBS and mice administered with a mouse IgG isotype control. Mice survival was monitored every day.

Results described in figure 12 showed that mice treated with 515H7 Mab had a dramatic and significant increase in life span with T/C% about 280 for 515H7 Mab (Figure 12).

Example 13: Anti-CXCR4 Mab 515H7 inhibition of T-cell KARPAS 299 xenograft tumor growth in Nod/Scid mice

The goal of this experiment was to evaluate the ability of anti-CXCR4 Mab 515H7 to inhibit the growth of KARPAS 299 xenograft in Nod/Scid mice.

KARPAS 299 cells from ECACC were routinely cultured in RPMI medium, 1% L-Glu and 10% FCS (Sigma, St Louis MD, USA). Cells were split 48 hours before engraftment so that they were in exponential phase of growth. Five million KARPAS 299 cells were engrafted in PBS to 7 weeks old Nod/SCID mice (Charles River, France). Five days after implantation, tumors were measurable (32 mm^3<V^3<49 mm^3) and animals were divided into groups of 6 mice with comparable tumor size. Mice were treated i.p. with a 2 mg/mouse loading dose of Mab 515H7.

Then, mice were injected twice a week at 1 mg/dose/mouse of Mab 515H7. A PBS group was introduced as a control group in this experiment. Tumor volume was measured twice a week and calculated by the formula: $\pi/6$ X length X width X height. Statistical analysis were performed at each measure using a Mann-Whitney test.

In these experiments, no mortality was observed during treatment. Compared to PBS group, there was a significant inhibition of tumor growth between D7 and D33 ($p \leq 0.002$) for 515H7 Mab 1mg/dose and the average tumor volume after 5 weeks of treatment was reduced by 63% for Mab 515H7 versus PBS (Figure 13).

Example 14: Production of anti-CXCR4 chimeric Mab c515H7

Chimeric formats of murine 515H7 Mab was designed: it corresponds to the light and heavy chain variable domains of the murine antibody of interest, genetically fused to human Ckappa and IgG1 constant domains. Recombinant Mab was produced

upon transient transfection by using the HEK293/EBNA system with a pCEP4 expression vector (InVitrogen, US).

The entire nucleotide sequences corresponding to the variable domains of 515H7 Mab light and heavy chains were synthesized by global gene synthesis (Genecust, Luxembourg). They were subcloned into a pCEP4 vector (InVitrogen, US) carrying the entire coding sequence of the constant domain of either the light [Ckappa] or the heavy [CH1-Hinge-CH2-CH3] chain of a human IgG1 immunoglobulin. All cloning steps were performed according to conventional molecular biology techniques as described in the Laboratory manual (Sambrook and Russel, 2001) or according to the supplier's instructions. Each genetic construct was fully validated by nucleotide sequencing using Big Dye terminator cycle sequencing kit (Applied Biosystems, US) and analyzed using a 3100 Genetic Analyzer (Applied Biosystems, US).

Suspension-adapted HEK293 EBNA cells (InVitrogen, US) were routinely grown in 250 ml flasks in 50 ml of serum-free medium Excell 293 (SAFC Biosciences) supplemented with 6 mM glutamine on an orbital shaker (110 rpm rotation speed). Transient transfection was performed with 2.10^6 cells/ml using linear 25 kDa polyethyleneimine (PEI) (Polysciences) prepared in water at a final concentration of 1 mg/ml mixed and plasmid DNA (final concentration of 1.25 µg/ml for heavy to light chain plasmid ratio of 1:1). At 4 hours post-transfection, the culture was diluted with one volume of fresh culture medium to achieve a final cell density of 10^6 cells/ml. Cultivation process was monitored on the basis of cell viability and Mab production. Typically, cultures were maintained for 4 to 5 days. Mab was purified using a conventional chromatography approach on a Protein A resin (GE Healthcare, US). Mab was produced at levels suitable with functional evaluations. Productivity levels are typically ranging between 6 and 15 mg/l of purified Mab.

Example 15: Characterization by FACS analysis of anti-CXCR4 chimeric Mab c515H7 binding specificity and cancer cell line recognition

In this experiment, specific binding to human CXCR4 of anti-CXCR4 chimeric Mab c515H7 was examined by FACS analysis.

NIH3T3, NIH3T3-hCXCR4 transfected cells and MDA-MB-231 cancer cell line were incubated with 10 µg/mL of monoclonal antibody c515H7. The cells were then

washed with 1%BSA/PBS/0.01% NaN3. Next, Alexa-labeled secondary antibodies were added to the cells and were allowed to incubate at 4°C for 20 min. The cells were then washed again two times. Following the second wash, FACS analysis was performed. Results of these binding studies are provided in the following Table 7 which shows [Mean Fluorescence Intensity (MFI) obtained by FACS] that anti-CXCR4 chimeric Mab c515H7 bounds specifically to human CXCR4-NIH3T3 transfected cell line and also recognize human cancer cell lines, for example MDA-MB-231 breast cancer cells.

Table 7

Mab (10 µg/ml)	MFI on cell lines	
	NIH3T3-CXCR4	MDA-MB-231
c515H7	2294	118

Example 16: Competition binding of anti-CXCR4 murine Mab m515H7 and chimeric Mab c515H7 for [^{125}I]SDF-1 at CHO-K1 membranes stably expressing human CXCR4 receptor

This assay allows to evaluate the ability of murine Mab m515H7 and chimeric Mab c515H7 to compete for binding of radio labeled [^{125}I]SDF-1 to human CXCR4 receptor, at either orthosteric or allosteric binding sites.

CHO-K1 cells, stably and constitutively expressing human CXCR4 receptor were obtained upon transfection of naïve CHO-K1 cells (ATCC CCL-61) with a mammalian expression vector carrying the whole coding sequence of human CXCR4 receptor (RefSeq NM_003467). Cells were propagated in complete culture medium [DMEM-Ham's F12 supplemented with 5 % fetal calf serum (FCS) and 500 µg/ml of geneticin]. Radioligand binding experiments were conducted on cell membranes obtained upon mechanical scrapping of CHO/CXCR4 cells in lysis buffer [Hepes 20mM, pH 7.4, NaCl 150mM] followed by centrifugation (10000g, 15 min). [^{125}I]SDF-1 binding (specific activity: 1500 Ci/mmol) was performed using the SPA technology (scintillation proximity assay – GE Healthcare). Briefly, cell membranes (30 µg/well) were incubated in binding buffer [Hepes 20mM, pH 7.4, $CaCl_2$ 1mM, $MgCl_2$ 5mM, NaCl 150mM, BSA 1%] together with compound to evaluate (SDF-1 or mAb),

radioligand (1 nM) and finally SPA-WGA-PVT beads (7.3 mg/well). Binding equilibrium was reach after 1H at 25 °C. Upon centrifugation [1000 g for 10 min.] radioactive counts were measured in a scintillation counter (TopCount, Perkin Elmer). Non-specific (NS) binding was estimated in the presence of 10 µM of unlabelled SDF-1.

Anti-CXCR4 Mabs (100 nM) efficiently competed for [^{125}I]SDF-1 binding with the following rank order of competition efficacy (% inhibition of [^{125}I]SDF-1): m515H7 (62±10%) and c515H7 (55±4%) (Figure 14).

Example 17: Modulation of [^{35}S]GTPγS binding at cellular membranes expressing wild type CXCR4 receptor by anti-CXCR4 murine Mab m515H7 and chimeric Mab c515H7

This functional assay allows to monitor G protein activation via wild type human CXCR4 receptor and its modulation by anti-CXCR4 murine Mab m515H7 and chimeric Mab c515H7.

NIH-3T3 cells stably and constitutively expressing wild-type CXCR4 receptor were obtained as described in the example above for CHO-K1 cells. HeLa (human cervix carcinoma) cells were propagated in complete culture medium [EMEM supplemented with 10% FCS, 1% L-glutamine, 2 µM sodium bicarbonate]. [^{35}S]GTPγS binding was performed on cellular membranes obtained upon mechanical scrapping in lysis buffer [Hepes 20mM, pH 7.4, NaCl 150mM] and further centrifugation (10000 g, 15 min). Incorporation and detection of [^{35}S]GTPγS (specific activity: 1000 Ci/mmol) was performed using the SPA technology (scintillation proximity assay - GE Healthcare). Briefly, cell membranes (10 µg/well) were incubated in binding buffer [Hepes 20mM, GDP 3µM, $MgCl_2$ 10mM, NaCl 100mM, EDTA 1mM, pH=7.4] together with compound to evaluate (SDF-1 and Mab of interest), [^{35}S]GTPγS (0.2-0.4 nM) and finally SPA-WGA-PVT beads (7.3 mg/well). Binding reaction was performed during 1H at 25°C. Upon centrifugation [1000 g for 10 min.] radioactive counts were measured in a scintillation counter (TopCount, Perkin Elmer). IC_{50} were calculated for each Mab.

Under these experimental conditions, IC_{50} of m515H7 and c515H7 Mabs, as determined in NIH3T3/CXCR4 cells were 1.9 nM and 1.5 nM, respectively (Figure 15).

The IC_{50} of m515H7 and c515H7 Mabs determined using Hela cells in the same experimental conditions were 0.2 nM and 0.6 nM, respectively (Figure 16).

Example 18: Association of CXCR4 with different interaction partners: homo and heterodimerization, recruitment of β-arrestin via a bioluminescence resonance energy transfer (BRET) approach and effect of murine Mab m515H7 and chimeric Mab c515H7 on these dimers

This functional assay allows to evaluate the conformational changes induced upon SDF-1 and/or m515H7 murine Mab and c515H7 chimeric Mab binding to CXCR4 receptor at the level of CXCR4 homo-dimer and CXCR2/CXCR4 hetero-dimer formation as well as the recruitment of the β-arrestin-2 signaling protein.

Expression vectors for each of the investigated interaction partners were constructed as fusion proteins with the corresponding dye (*Renilla reniformis* luciferase, Rluc and Yellow fluorescent protein, YFP) by applying conventional molecular biology techniques. Two days prior performing BRET experiments, HEK293 cells were transiently transfected with expression vectors coding for the corresponding BRET partners: [CXCR4/Rluc + CXCR4/YFP] to study CXCR4 homo dimerization, [CXCR4-Rluc + CXCR2-YFP] to study CXCR4 and CXCR2 hetero-dimerization and [CXCR4-Rluc + β-arr2-YFP] to study CXCR4-mediated recruitment of β-arrestin-2. The day after, cells were distributed in poly-lysine pre-coated white 96 MW plates in complete culture medium [DMEM supplemented with 10 % FBS]. Cells were first cultivated at 37°C with CO_2 5 % in order to allow cell attachment to the plate. Cells were then starved with 200 µl DMEM/well overnight. Immediately prior to the BRET experiment, DMEM was removed and cells were quickly washed with PBS. Cells were then incubated in PBS in the presence or absence of antibody, 15 min at 37°C prior to the addition of coelenterazine H 5 µM with or without SDF-1 100 nM in a final volume of 50 µl. After incubation for 5 minutes at 37°C and further incubation for 20 min at room temperature only for homo and hetero-dimers, light-emission acquisition at 485 nm and 530 nm was initiated using the Mithras LB940 multilabel reader (Berthold) (1s/wavelength/well repeated 15 times at room temperature).

Calculation of BRET ratio was performed as previously described (Angers et al., 2000): $[(\text{emission}_{530\ nm}) - (\text{emission}_{485\ nm}) \times Cf] / (\text{emission}_{485\ nm})$, where Cf =

(emission$_{530\ nm}$) / (emission$_{485\ nm}$) for cells expressing the Rluc fusion protein alone under the same experimental conditions. Simplifying this equation shows that BRET ratio corresponds to the ratio 530/485 nm obtained when the two BRET partners are present, corrected by the ratio 530/485 nm obtained under the same experimental conditions, when only the partner fused to Rluc is present in the assay. For sake of readability, results are expressed in milliBRET units (mBU); mBU corresponds to the BRET ratio multiplied by 1000.

SDF1 (100 nM) increased by about 10 % the BRET signal resulting from the spatial proximity of the donor and acceptor proteins fused to CXCR4 receptor, it is likely to indicate CXCR4/CXCR4 homo-dimers formation or conformational changes of pre-existing dimers (Figure 17A). Interestingly, SDF1 (100 nM) decreased by about 17 % the BRET signal resulting from the spatial proximity of the donor and acceptor proteins fused to CXCR4 and CXCR2, likely indicating as well CXCR2/CXCR4 hetero-dimers formation or conformational changes of pre-existing dimers (Figure 17B). In this latter case, SDF-1-activated conformation of CXCR4/CXCR2 seems less favorable for BRET energy transfer. In both cases, m515H7 and c515H7 Mabs were able to modulate SDF-1-induced conformational changes for CXCR4 homo-dimers (96% inhibition of SDF-1-induced BRET increase for c515H7, Figure 17A) as well as for CXCR2/CXCR4 hetero-dimer formation (98 % inhibition of SDF-1-induced BRET decrease for c515H7, Figure 17B). m515H7 and c515H7 Mabs were also able to modulate by themselves CXCR4/CXCR4 and CXCR2/CXCR4 spatial proximity respectively, indicating an influence of these Mabs on both CXCR4/CXCR4 homo and CXCR2/CXCR4 hetero-dimer conformation (Figures 17A and 17B).

CXCR4 activation by SDF-1 (100 nM) yielded a strong recruitment of the intracellular signaling molecule β-arrestin, as shown by the 400 % enhancement in BRET signal (Figure17C). This recruitment was partially inhibited by c515H7 Mab (about 93%, Figure 17C) showing the effect of these Mabs on signaling.

Example 19: CXCR4 receptor-mediated mobilization of intracellular calcium stores

This functional assay was designed to monitor CXCR4 receptor signaling via stimulation of the phospholipase C pathway, inducing calcium liberation from intracellular stores from the endoplasmic reticulum.

CHO-K1 cells stably and constitutively expressing wild-type CXCR4 receptor were obtained as described in the example above. U937 (human leukemia) cells were propagated in complete culture medium, respectively [DMEM supplemented with 10% FCS] and [RPMI 1640 supplemented with 10% FCS, 20 mM HEPES, 1% non-essential amino acid solution, 1% sodium pyruvate, 1% L-glutamine, 4.5 g/l glucose]. All cell types were plated in black 96MW plates at a density of 100,000 cells/well in appropriate culture medium. Cells were starved overnight before conducting the experiments. Cells were loaded with the fluorescent calcium dye (Fluo-4 No Wash, Invitrogen US) in loading buffer [HBSS 1x, HEPES 20 mM, Probenicid acid 25 mM] for 30 min. at 37°C followed by 30 min. at 25°C. Stimulation by SDF-1 was performed by direct injection into each well. For antagonism experiments, 10 µl of Mab solution were added directly into the loading buffer at least 10 min. before SDF-1. Kinetic fluorescence measurements were performed on a multi-mode fluorescence microplate reader Mithras LB940 (Berthold) using the following settings: excitation at 485 nm, emission at 535 nm, excitation energy at 10000 arbitrary units. Fluorescence in each well was recorded during 0.1 second every second and for a time period of 20 sec prior SDF-1 injection (basal signal). Then 20 µl of SDF-1 were injected and data recording followed for a time period of 2 min. Each experimental condition was performed in duplicate. Values for each well were first corrected by substracting the basal fluorescence and the fluorescence emitted by a control well without cells. Relative data were expressed as a percentage of the maximal stimulation obtained by SDF-1 (100 nM).

SDF1 (100 nM) induced a rapid and strong release of intracellular calcium in recombinant CHO/CXCR4, whereas no fluorescence signal was detected in naïve CHO-K1 cells. The maximal intensity reached > 140 % over basal fluorescence and was observed at about 40 sec. upon stimulation by SDF-1; similar kinetic curves were observed with U-937 cells (Figures 18A, 18B). Chimeric antibody c515H7 (133 nM) yielded a strong and almost complete inhibition of the SDF-1 (100 nM)-induced calcium signal in both investigated cell lines.

Example 20: Effect of anti-CXCR4 murine Mab m515H7 and chimeric Mab c515H7 on SDF-1-induced U937 cells migration

To evaluate the inhibiting effect of the anti-CXCR4 Mabs m515H7 and c515H7 on the migration process, 100 000 U-937 cells in RPMI 1640 medium supplemented with 2% FCS, were plated in the upper chamber of migration chambers (24 wells plates with 8-µm pore size) either in presence or in absence of SDF-1 in the lower part of the wells and with or without Mabs c515H7 and m515H7 in the upper chamber. In this test murine IgG2b was introduced as an isotype control. Two hours after plating, migrating cells were counted. The results presented in figure 19 demonstrated that, as expected SDF-1 was able to induce a significant increase of U-937 cells migration. No effect was observed when cells were incubated with the IgG2 isotype control. In contrast, for cells incubated with the c515H7 and m515H7 Mabs, a significant and reproducible decrease in SDF-1-induced U937 cells migration was observed: about more than 80% with c515H7 and m515H7 Mabs.

Example 21: Anti-CXCR4 chimeric Mab c515H7 activity in U937 mice survival model

U937 cells from ATCC were cultured in RPMI 1640 medium, 10% FCS, 1% L-Glutamine. Cells were split two days before engraftment so that they were in exponential phase of growth. Ten million U937 cells injected i.p. to female NOD/SCID mice. Two days after implantation, mice were treated s.c. with a loading dose of 2 mg of c515H7 Mab/mouse and then twice a week with 1 mg of antibody/mouse. Control mice received PBS injections as it has been shown in previous studies that no difference in survival was observed between mice injected with PBS and mice administered with a mouse IgG isotype control. Mice survival was monitored every day.

Results described in figure 20 showed that mice treated with the c515H7 Mab had a dramatic and significant increase in life span with T/C% of about 180.

Example 22: Humanization of 515H7 anti-CXCR4 murine antibody

General procedure

Humanization of 515H7 anti-CXCR4 antibody was performed by applying the global rules of CDR-grafting. Immunogenetic analysis and definition of CDR and

framework (FR) regions were performed by applying the IMGT unique numbering scheme as well as the IMGT libraries and tools (Lefranc, 1997 – www.imgt.org).

The efficiency of the humanization process was evaluated by testing the functional activity of the engineered antibodies for their ability to inhibit the SDF-1-mediated recruitment of β-arrestin by a Bioluminescence Resonance Energy Transfer (BRET) assay. In this assay CXCR4 was tagged with luciferase and β-arrestin with YFP. The SDF-1 mediated recruitment of β-arrestin to CXCR4 is an important step in the signal transduction of CXCR4. Binding of humanized variants of 515H7 was also determined on a NIH3T3 cell line stably transfected with human CXCR4. The binding activity was evaluated by a competition assay with the biotinylated mouse antibody. In a second attempt, humanized antibodies were evaluated for their ability to inhibit binding of biotinylated SDF-1 to RAMOS cells. RAMOS cells were chosen because of their high expression of CXCR4 and low expression of CXCR7 and SDF-1.

These assays were used to characterize the recombinant humanized versions of anti-CXCR4 antibodies. Variable domains were formatted with human IgG1/k constant domains and cloned into the mammalian expression vector pCEP. Recombinant IgG_1/κ-derived antibodies were transiently expressed in HEK293 cells. Expression culture supernatants were filtered and antibodies were purified using protein A sepharose. Purified antibodies were re-buffered in PBS and antibodies concentrations determined by ELISA.

Humanization of 515H7 variable domains

In order to select an appropriate human germline for the CDR grafting, the human germline gene with the highest homology to the 515H7 VH murine sequence was identified. With the help of IMGT databases and tools, the human IGHV3-49*04 germline gene and human IGHJ4*01 J germline gene were selected as human acceptor sequences for the murine 515H7 VH CDRs. The human V-gene IGHV3-49*04 has a homology of 80.27% to the V-gene of the variable domain of the mouse 515H7 heavy chain. The homology for the human J-gene IGHJ4*01 J is 87.50%. Nineteen residues are different between the chosen human germline genes and the VH domain of the mouse antibody 515H7. The alignment between the VH domain of the parental antibody and the germline sequences is depicted in Figure 21.

Concerning the variable domain of the light chain, the human germline genes IGKV4-1*01 and IGKJ1*01 were selected (Figure 22). The homology with human V-gene IGKV4-1*01 is 79.12%. The 515H7 J-gene of the light chain has a homology of 84.85% to the human J-gene IGKJ1*01.

The amino acid sequence of the translated human germline genes IGHV3-49*04 and IGKV4-1*01 was used to identify homologous antibodies that have been crystallized. For the heavy chain the antibody with the accession number 1MAM at the RCSB Protein Data Bank was chosen as a model, while for the light chain the antibody 1SBS was chosen. The two domains were assembled using the computer program DS visual and used as a model for the humanized antibody 515H7.

Based on the position of each residue that is different between the parental antibody and the corresponding human germline sequence, a priority rank order was given for each residue differing between the human and mouse sequences (Figures 21 and 22). These priorities were used to create three different variants of each humanized variable domain named VH1, VH2 and VH3, respectively.

In a first series of experiments, we constructed and analysed the anti-CXCR4 binding activities of the three first humanized variants. The VH variant 1 (VH1) was combined with the murine VL and these constructs were evaluated in their capacity to inhibit the binding of a biotinylated murine 515H7 parental antibody. All constructs showed similar capacity to compete with the murine antibody (Figure 23A-C). This indicates that the most human VH variant has the same binding capacity as the lesser human variants. Therefore, VH1 was combined with the three different variants of VL (Figure 23D-F). Only the combination of VH1 and VL3 showed a reduced capacity to compete with the biotinylated murine antibody, while the most human variant VH1 VL1 that carries no back mutations in the frameworks showed the same cross blocking activity as the chimeric antibody.

This variant VH1 VL1 was further tested for its capacity to inhibit SDF-1 mediated recruitment of β-arrestin in BRET assays (Figure 24). Despite desirable binding activity to the receptor as determined by cross blocking of the parental antibody, the construct VH1 VL1 showed only a weak inhibition of the recruitment of β-arrestin. This lack of strong inhibitory activity makes substitution of human framework residues with murine residues necessary. Single back mutations were

constructed for the VH 1. The following residues were substituted: V48L, E61D, D76N and A81L (numbering according to the primary amino acid sequence). These single back mutants of the variant VH1 were combined with the variant VL1. Of these only the back mutation D76N led to an increased inhibition of the signal transduction as evaluated by BRET assay (Figure 25B).

To increase the activity of this construct and further evaluate the importance of other residues different double back mutants were constructed for the VH 1. The inhibitory activity of these constructs was slightly improved (average inhibition of about 45-50 %), but not satisfactory (Figure 25C). The single back mutant D76N was then combined with the three different VL variants (Figure 25D). The construct hz515H7 VH D76N VL2 showed an activity of 88.2 % on average which is in the same range as the chimeric antibody.

Single and double back mutations were constructed in the variant VL1 domain and compared to the activity of the construct hz515H7 VH1 D76N VL2 (Figure 26). None of the tested combinations had a similar or better activity as this construct.

The percentage of human residues in the framework was calculated for hz515H7 VH1 D76N VL2: it contains 14 non-human residues out of 180 residues, which equals a « germinality index » of 92.2 %. By way of comparison, the humanized and marketed antibodies bevacizumab and trastuzumab contain respectively 30 and 14 non-human residues in their variable domains.

The four best humanized forms, showing the strongest efficacy to inhibit SDF-1-mediated β-arrestin recruitment were also tested for their capacity to inhibit the binding of biotinylated SDF-1 (Figure 27A). A close correlation of inhibition of SDF-1 binding and β-arrestin recruitment was determined. This correlation indicates that the inhibition of SDF-1 binding is most likely the main mechanism of the inhibition of the signal transduction.

In order to further humanize the hz515H7 VH1 D76N VL2 variant, three additional variants were designed, by using the information gained with the double and triple mutants evaluated in Figure 26. Four and five additional residues were humanized in respectively variant VL2.1, VL2.2 and VL2.3 (also referred as VL2-1, VL2-2 and VL2-3). They correspond to the residues D9, P49, D66, S69, S83, L84; V89. An alignment of these three variants in comparison with VL2 is shown Figure 28.

The capacity of these VL2 variants to inhibit the SDF-1 mediated recruitment of β-arrestin was evaluated. The humanized hz515H7 VH1 D76N VL2, VL2.1, VL2.2 and VL2.3 variants showed an activity similar to the chimeric antibody c515H7 (Figure 26).

Humanization of 515H7-2 variable domains

In order to generate another humanized form, another appropriate human germline for the CDR grafting, both for the variable domain of the light and the heavy chains, was selected. For both of them, the germline was selected, not only regarding to the percentage of homology with the murine sequence, but also as they have the same CDR length as the VL and VH, respectively, of the murine 515H7.

With the help of IMGT databases and tools, the human IGHV3-73*01 germline gene and human IGHJ4*01 J germline gene were selected as human acceptor sequences for the murine 515H7 VH CDRs. The human V-gene IGHV3-73*01 has a homology greater than 79 % to the V-gene of the variable domain of the mouse 515H7 heavy chain. The homology for the human J-gene IGHJ4*01 J is 87.50%.

Concerning the variable domain of the light chain, the human germline genes IGKV2D-40*01 and IGKJ1*01 were selected. The homology with human V-gene IGKV2D-40*01 is greater than 70 %. The 515H7 J-gene of the light chain has a homology of 84.85% to the human J-gene IGKJ1*01.

Based on the position of each residue that is different between the parental antibody and the corresponding human germline sequence, and the knowledge of the man skilled in the art, several critical residues were identified as residues being to be back-mutated.

Regarding the heavy chain, these residues are H35S, V48L, R50F, A61D, D76N and/or A81L (see SEQ ID Nos. 86 and 90 of Table 2c).

With respect to the light chain, these residues are L9S, I21M, D40A, L43Q, Y59A, A61D, D66A, S69T, G74E, D76Y and/orV89L (see SEQ ID Nos. 85 and 89 of Table 2c).

Example 23: Characterization by FACS analysis of anti-CXCR4 humanized Mabs 515H7 binding specificity and cancer cell line recognition

In this experiment, specific binding to human CXCR4 of anti-CXCR4 humanized Mabs 515H7 was examined by FACS analysis.

NIH3T3, NIH3T3-hCXCR4 transfected cells and Ramos, U934 cancer cell lines were incubated with 0 to 10 µg/mL of humanized Mabs 515H7 (hz515H7 VH1 D76N VL2 [=hz515H7VL2], hz515H7 VH1 D76N VL2.1 [=hz515H7VL2.1], hz515H7 VH1 D76N VL2.2 [=hz515H7VL2.2] and hz515H7 VH1 D76N VL2.3 [=hz515H7VL2.3]) for 20 min at 4°C in the dark in 100 µl Facs buffer. After 3 washing in Facs buffer, cells were incubated with the secondary antibody, a goat anti-human Alexa 488 (dilution 1/500), for 20 minutes at 4°C in the dark. After 3 washing in Facs buffer, propidium iodide was added in each well and only viable cells were analyzed by Facs. At least 5000 viable cells were assessed to evaluate the mean value of fluorescence intensity for each condition.

Results of these binding studies are provided in Figures 29A-29C which show [Mean Fluorescence Intensity (MFI) obtained by FACS] that anti-CXCR4 humanized Mabs hz515H7 bound specifically to human CXCR4-NIH3T3 transfected cell line (Figure 29A) (MFI= 2.2 with NIH3T3 parent cells) and also recognize human cancer cell lines, for example U937 (Figure 29B) and Ramos (Figure 29C).

Example 24: Modulation of [^{35}S]GTPγS binding at cellular membranes expressing wild type CXCR4 receptor by anti-CXCR4 humanized Mabs 515H7

This functional assay allows to monitor G protein activation via wild type human CXCR4 receptor and its modulation by anti-CXCR4 humanized Mabs 515H7.

NIH-3T3 cells stably and constitutively expressing wild-type CXCR4 receptor were obtained as described in the example above for CHO-K1 cells. [^{35}S]GTPγS binding was performed on cellular membranes obtained upon mechanical scrapping in lysis buffer [Hepes 20mM, pH 7.4, NaCl 150mM] and further centrifugation (10000 g, 15 min). Incorporation and detection of [^{35}S]GTPγS (specific activity: 1000 Ci/mmol) was performed using the SPA technology (scintillation proximity assay - GE Healthcare). Briefly, cell membranes (10 µg/well) were incubated in binding buffer [Hepes 20mM, GDP 3µM, $MgCl_2$ 10mM, NaCl 100mM, EDTA 1mM, pH=7.4] together with compound to evaluate (SDF-1 and Mabs of interest), [^{35}S]GTPγS (0.2-0.4 nM) and finally SPA-WGA-PVT beads (7.3 mg/well). Binding reaction was

performed during 1H at 25°C. Upon centrifugation [1000 g for 10 min.] radioactive counts were measured in a scintillation counter (TopCount, Perkin Elmer). IC_{50} were calculated for each Mab.

Under these experimental conditions, IC_{50} of humanized (hz) 515H7 Mabs, as determined in NIH3T3/CXCR4 cells were 3.86 nM for hz515H7 VH1 D76N VL2 Mab (Figure 30A), 4.05 nM for hz515H7 VH1 D76N VL2-1 Mab (Figure 30B), 5.19 nM for hz515H7 VH1 D76N VL2-2 Mab (Figure 30C) and 8.5 nM for hz515H7 VH1 D76N VL2-3 Mab (figure 30D).

hz515H7 Mabs were also able to inhibit [^{35}S]GTPγS binding stimulated by SDF-1 (100nM) with a % of inhibition of 86% for hz515H7 VH1 D76N VL2 Mab, 69% for hz515H7 VH1 D76N VL2-1 Mab, 66% for hz515H7 VH1 D76N VL2-2 Mab 58% for hz515H7 VH1 D76N VL2-3 Mab (Figure 31).

Example 25: Association of CXCR4 with different interaction partners: homo and heterodimerization, recruitment of β-arrestin via a bioluminescence resonance energy transfer (BRET) approach and effect of humanized Mabs 515H7 on these dimers

This functional assay allows to evaluate the conformational changes induced upon SDF-1 and/or 515H7 humanized Mabs binding to CXCR4 receptor at the level of CXCR4 homo-dimer and CXCR2/CXCR4 hetero-dimer formation as well as the recruitment of the β-arrestin-2 signaling protein.

Expression vectors for each of the investigated interaction partners were constructed as fusion proteins with the corresponding dye (*Renilla reniformis* luciferase, Rluc and Yellow fluorescent protein, YFP) by applying conventional molecular biology techniques. Two days prior performing BRET experiments, HEK293 cells were transiently transfected with expression vectors coding for the corresponding BRET partners: [CXCR4/Rluc + CXCR4/YFP] to study CXCR4 homo dimerization, [CXCR4-Rluc + CXCR2-YFP] to study CXCR4 and CXCR2 hetero-dimerization and [CXCR4-Rluc + β-arr2-YFP] to study CXCR4-mediated recruitment of β-arrestin-2. The day after, cells were distributed in poly-lysine pre-coated white 96 MW plates in complete culture medium [DMEM supplemented with 10 % FBS]. Cells were first cultivated at 37°C with CO_2 5 % in order to allow cell attachment to the plate. Cells were then

starved with 200 µl DMEM/well overnight. Immediately prior to the BRET experiment, DMEM was removed and cells were quickly washed with PBS. Cells were then incubated in PBS in the presence or absence of antibody, 15 min at 37°C prior to the addition of coelenterazine H 5 µM with or without SDF-1 100 nM in a final volume of 50 µl. After incubation for 5 minutes at 37°C and further incubation for 20 min at room temperature only for homo- and hetero-dimers, light-emission acquisition at 485 nm and 530 nm was initiated using the Mithras LB940 multilabel reader (Berthold) (1s/wavelength/well repeated 15 times at room temperature).

Calculation of BRET ratio was performed as previously described (Angers et al., 2000): [(emission$_{530\ nm}$) - (emission$_{485\ nm}$) X Cf] / (emission$_{485\ nm}$), where Cf = (emission$_{530\ nm}$) / (emission$_{485\ nm}$) for cells expressing the Rluc fusion protein alone under the same experimental conditions. Simplifying this equation shows that BRET ratio corresponds to the ratio 530/485 nm obtained when the two BRET partners are present, corrected by the ratio 530/485 nm obtained under the same experimental conditions, when only the partner fused to Rluc is present in the assay. For sake of readability, results are expressed in milliBRET units (mBU); mBU corresponds to the BRET ratio multiplied by 1000.

SDF1 (100 nM) increased by about 12 % the BRET signal resulting from the spatial proximity of the donor and acceptor proteins fused to CXCR4 receptor, it is likely to indicate CXCR4/CXCR4 homo-dimers formation or conformational changes of pre-existing dimers (Figure 32A). Interestingly, SDF1 (100 nM) decreased by about 16 % the BRET signal resulting from the spatial proximity of the donor and acceptor proteins fused to CXCR4 and CXCR2, likely indicating as well CXCR2/CXCR4 hetero-dimers formation or conformational changes of pre-existing dimers (Figure 32B). In this latter case, SDF-1-activated conformation of CXCR4/CXCR2 seems less favorable for BRET energy transfer. In both cases, 515H7 humanized Mabs were able to modulate SDF-1-induced conformational changes for CXCR4 homo-dimers with a percentage of inhibition of SDF-1-induced BRET increase of about 88% for hz515H7 VH1D76N-VL2 Mab, 65% for hz515H7 VH1D76N-VL2.1 Mab, 33% for hz515H7 VH1D76N-VL2.2 Mab and 21% for hz515H7 VH1D76N-VL2.3 Mab (Figure 32A) as well as for CXCR2/CXCR4 hetero-dimer with a percentage of inhibition of SDF-1-induced BRET decrease about 100% for hz515H7 VH1D76N-VL2 Mab and 50% for

hz515H7 VH1D76N-VL2.1, hz515H7 VH1D76N-VL2.2 and hz515H7 VH1D76N-VL2.3 Mabs (Figure 32B). 515H7 humanized Mabs were also able to modulate by themselves CXCR4/CXCR4 and CXCR2/CXCR4 spatial proximity respectively, indicating an influence of these Mabs on both CXCR4/CXCR4 homo and CXCR2/CXCR4 hetero-dimer conformation (Figures 32A and 32B).

CXCR4 activation by SDF-1 (100 nM) yielded a strong recruitment of the intracellular signaling molecule β-arrestin, as shown by the 390 % enhancement in BRET signal (Figure 32C). This recruitment was partially inhibited by 515H7 humanized Mabs about 94 % inhibition for hz515H7 VH1D76N-VL2 Mab, 81% for hz515H7 VH1D76N-VL2.1 Mab, 82% for hz515H7 VH1D76N-VL2.2 Mab and 71% for hz515H7 VH1D76N-VL2.3 Mab (Figure 32C) showing the effect of these Mabs on signaling.

Example 26: Immunohistochemical Studies (IHC)

Sections were deparaffinized, rehydrated, and placed for 7 minutes in pre-warm at 98°C EDTA pH8 for heat-induced epitope retrieval. After 3 washes in Tris Buffer Saline-0.05% tween 20 (TBS-T) (Dako S3006) the endogenous peroxidase activity was blocked using Peroxidase Blocking Reagent (Dako K4007) for five minutes. Sections were washed with TBS-T and incubated in blocking reagent (UltraV block-TA-125UB-LabVision) for 5 minutes before incubation with the anti-CXCR-4 mouse monoclonal antibody (50 µg/ml, clone 515H7, Pierre Fabre) or mouse IgG1/kappa (50 µg/ml, X0931, Dako) as a control overnight at 4°C. Sections were washed with TBS-T and incubated with Envision Dual Link for 1 hour at room temperature. Diaminobenzidine was used for development of a brown reaction product (Dako K3468). The slides were immersed in hematoxylin for 4 minutes to counterstain (Dako S3309) and washed in PBS before being mounted in Faramount mounting medium plus coverslipe. In this immunohistochemistry procedure, the brown reaction product correlates to positive staining of the cell membrane and lack of brown reaction product correlates to negative staining and no visualization of the cell membrane.

The anti-CXCR4 mouse monoclonal antibody, clone 515H7, differentially stained the cell membrane of various tumor types. Figures 33 and 34 illustrated staining performed in 2 xenograft models in which an anti-tumoral activity has been described for 515H7:

RAMOS and KARPAS299. As shown in Figures 33 and 34, the staining obtained is fixative-dependant. Indeed, membranous staining was weaker when tissues were formalin fixed (Figures 34a and 34c), whereas, when Glyo-fixx (a substitute for formalin) was used, membranous staining was significantly increased (Figures 33a and 33c).

Example 27: Competition binding of anti-CXCR4 humanized Mabs 515H7 for [^{125}I]SDF-1 at CHO-K1 membranes stably expressing human CXCR4 receptor

This assay allows to evaluate the ability of humanized Mabs 515H7 to compete for binding of radio labeled [^{125}I]SDF-1 to human CXCR4 receptor, at either orthosteric or allosteric binding sites.

CHO-K1 cells, stably and constitutively expressing human CXCR4 receptor were obtained upon transfection of naïve CHO-K1 cells (ATCC CCL-61) with a mammalian expression vector carrying the whole coding sequence of human CXCR4 receptor (RefSeq NM_003467). Cells were propagated in complete culture medium [DMEM-Ham's F12 supplemented with 5 % fetal calf serum (FCS) and 500 µg/ml of geneticin]. Radioligand binding experiments were conducted on cell membranes obtained upon mechanical scrapping of CHO/CXCR4 cells in lysis buffer [Hepes 20mM, pH 7.4, NaCl 150mM] followed by centrifugation (10000g, 15 min). [^{125}I]SDF-1 binding (specific activity: 1500 Ci/mmol) was performed using the SPA technology (scintillation proximity assay – GE Healthcare). Briefly, cell membranes (30 µg/well) were incubated in binding buffer [Hepes 20mM, pH 7.4, $CaCl_2$ 1mM, $MgCl_2$ 5mM, NaCl 150mM, BSA 1%] together with compound to evaluate (SDF-1 or mAb), radioligand (1 nM) and finally SPA-WGA-PVT beads (7.3 mg/well). Binding equilibrium was reach after 1H at 25 °C. Upon centrifugation [1000 g for 10 min.] radioactive counts were measured in a scintillation counter (TopCount, Perkin Elmer). Non-specific (NS) binding was estimated in the presence of 10 µM of unlabelled SDF-1.

Anti-CXCR4 Mabs efficiently competed for [^{125}I]SDF-1 binding with the following rank order of competition efficacy (% inhibition of [^{125}I]SDF-1): hz515H7 VH1D76N VL2 (77%), hz515H7 VH1D76N VL2.1 (68%), hz515H7 VH1D76N VL2.2 (61%) and hz515H7 VH1D76N VL2.3 (49 %) (Figure 35A).

Hz515H7 Mabs dose-dependently inhibited [^{125}I]SDF-1 binding with IC_{50} of 1.44 nM for hz515H7 VH1D76N VL2 Mab (Figure 35B), 6.69 nM for hz515H7 VH1D76N VL2.1 Mab (Figure 35C), 5.91 nM for hz515H7 VH1D76N VL2.2 Mab (Figure 35D)

Example 28: CXCR4 receptor-mediated mobilization of intracellular calcium stores

This functional assay was designed to monitor CXCR4 receptor signaling via stimulation of the phospholipase C pathway, inducing calcium liberation from intracellular stores from the endoplasmic reticulum.

U937 (human leukemia) cells were propagated in complete culture medium [RPMI 1640 supplemented with 10% FCS, 20 mM HEPES, 1% non-essential amino acid solution, 1% sodium pyruvate, 1% L-glutamine, 4.5 g/l glucose]. Cells were plated in black 96MW plates at a density of 100 000 cells/well in appropriate culture medium and starved overnight before conducting the experiments. Cells were loaded with the fluorescent calcium dye (Fluo-4 No Wash, Invitrogen US) in loading buffer [HBSS 1x, HEPES 20 mM, Probenicid acid 25 mM] for 30 min. at 37 °C followed by 30 min. at 25°C. Stimulation by SDF-1 was performed by direct injection into each well. For antagonism experiments, 10 µl of Mab solution were added directly into the loading buffer at least 10 min. before SDF-1. Kinetic fluorescence measurements were performed on a multi-mode fluorescence microplate reader Mithras LB940 (Berthold) using the following settings: excitation at 485 nm, emission at 535 nm, excitation energy at 10000 arbitrary units. Fluorescence in each well was recorded during 0.1 second every second and for a time period of 20 sec prior SDF-1 injection (basal signal). Then 20 µl of SDF-1 were injected and data recording followed for a time period of 2 min. Each experimental condition was performed in duplicate. Values for each well are first corrected by substracting the basal fluorescence and the fluorescence emitted by a control well without cells. Relative data are expressed as a percentage of the maximal stimulation obtained by SDF-1 (100 nM).

SDF1 (100 nM) induced a rapid and strong release of intracellular calcium in U937 cells. The maximal intensity reached > 340 % over basal fluorescence and was observed at about 40 sec. upon stimulation by SDF-1. hz515H7 VH1D76N VL2 Mab (133 nM)

yielded partial inhibition of the SDF-1 (100 nM)-induced calcium signal in U937 cell lines (Figure 36 wherein said Mab is just referred as hz515H7VL2 in the legend).

Example 29: Effect of anti-CXCR4 humanized Mab hz515H7 on SDF-1-induced U937 cells migration

To evaluate the inhibiting effect of the anti-CXCR4 humanized Mab hz515H7 VH1D76N VL2 (referred as hz515H7) on the migration process, U937 cells were incubated with 10 µg/ml of antibodies for 40 minutes in RPMI1640 medium containing 2% FBS at 37°C in 5% CO2. A total of $5x10^4$ cells placed in the upper transwell chamber (Corning Lowell, MA, USA). In the lower chamber SDF-1 (100 ng/ml) was added in medium containing 2% FBS. Migration of U937 cells was measured by counting the number of cells that migrated from transwell chambers 2 hours after seeding cells into the upper chamber. Migrated cells were counted using the CellTiter-Glo® Luminescent Cell Viability Assay measuring the number of viable cells in culture based on quantification of the ATP.

The results presented in figure 37A demonstrated that, as expected SDF-1 was able to induce a significant increase of U-937 cells migration. No effect was observed when cells were incubated with the IgG1 isotype control. In contrast, Figure 37A shows inhibition of SDF1-induced U937 cells migration by 10 µg/ml of hz515H7 VH1 D76N VL2 Mab. Results represent the mean +/- SD of three independent experiments done in triplicate.

Figure 37B represents the effect of a dose range of hz515H7 VH1 D76N VL2 Mab on SDF-1induced cell migration. Results represent the mean +/- S.E.M of four independent experiments ($IC_{50} = 4.53\ 10^{-3}$ µg/ml +/- $2.2\ 10^{-3}$).

Example 30: Immunohistochemical Studies (IHC) with hz515H7 VH1 D76N VL2

Sections were deparaffinized, rehydrated, and placed for 7 minutes in pre-warm at 98°C EDTA pH8 for heat-induced epitope retrieval. After 3 washes in Tris Buffer Saline-0.05% tween 20 (TBS-T) (Dako S3006), the endogenous peroxidase activity was blocked using Peroxidase Blocking Reagent (Dako K4007) for five minutes. Sections were washed with TBS-T and incubated in blocking reagent (UltraV block-TA-125UB-

LabVision) for 5 minutes before incubation with the biotinylated humanized anti-CXCR4 antibody (50 µg/ml, hz515H7 VH1 D76N VL2, Pierre Fabre) or the biotinylated human IgG1 (50 µg/ml, BP078, The Binding Site) as an isotype control overnight at 4°C. Sections were washed with TBS-T and incubated with streptavidin HRP for 1 hour at room temperature. Diaminobenzidine was used for development of a brown reaction product (Dako K3468). The slides were immersed in hematoxylin for 4 minutes to counterstain (Dako S3309) and washed in PBS before being mounted in Faramount mounting medium plus coverslipe. In this immunohistochemistry procedure, the brown reaction product correlates to positive staining of the cell membrane and lack of brown reaction product correlates to negative staining and no visualization of the cell membrane.

The biotinylated anti-CXCR4 humanized antibody 515H7 VH1 D76N VL2, differentially stains the cell membrane of various tumor types. Figures 38 and 39 illustrated stainings performed in 2 xenograft models in which an anti-tumoral activity is described when mice were treated with 515H7: RAMOS and KARPAS299. As shown in Figures 38 and 39, the staining obtained is fixative-dependant. Indeed, membranous staining is weaker when tissue were formalin fixed (Figure 39a and 39c), whereas, when Glyo-fixx (a substitute for formalin) was used, membranous staining is significantly increased (Figure 38a and 38c)

Example 31: Effect of chimeric 515H7 (c515H7), humanized forms hz515H7 VH1D76N VL2 and hz515H7 VH1 D76N VL2.1 Mabs on B-cell Ramos xenograft tumor growth in Scid mice

Ramos cells from ATCC were routinely cultured in RPMI 1640 medium, 10% FCS and 2mM L-Glu (Sigma, St Louis MD, USA). Cells were split 48 hours before engraftment so that they were in exponential phase of growth. Ten million Ramos cells were engrafted in PBS sc. to 7 weeks old female SCID mice (Charles River, France). Five days after implantation, tumors were measurable (mean 100 mm^3) and animals were divided into groups of 6 mice with comparable tumor size. Mice were treated i.p. with a 2 mg/mouse loading dose of Mabs c515H7, hz515H7 VH1D76N VL2 or hz515H7 VH1 D76N VL2.1. Then, mice were injected twice a week at 1 mg/dose/mouse of Mabs c515H7, hz515H7 VH1 D76N VL2 or hz515H7VH1 D76N

VL2.1. A PBS group was introduced as a control group in this experiment. Tumor volume was measured twice a week and calculated by the formula: $\pi/6$ X length X width X height. Statistical analyses were performed at each measure using a Mann-Whitney test.

In these experiments, no mortality was observed during treatment. Compared to PBS group, there was a significant inhibition of tumor growth between D11 and D54 for c515H7 Mab (Figure 40) hz515H7 VH1 D76N VL2 Mab (Figure 41) and hz515H7 VH1 D76N VL2.1 (Figure 42) 1mg/dose and the average tumor volume after 4 weeks of treatment was reduced by 92% for mice treated with c515H7 and hz515H7 Mabs versus PBS group.

CLAIMS

1. A humanized antibody capable of binding specifically to CXCR4, or a derived compound or functional fragment of same, characterized in that the said humanized antibody, or derived compound of functional fragment of same, comprises heavy and light chains, said heavy chain having CDRs consisting of CDR-H1, CDR-H2 and CDR-H3, and the said light chain having CDRs consisting of CDR-L1, CDR-L2 and CDR-L3, wherein said CDR-H1, CDR-H2 and CDR-H3 comprise respectively the sequences SEQ ID Nos. 4, 5 and 6, and said CDR-L1, CDR-L2 and CDR-L3 comprise respectively the sequences SEQ ID Nos. 7, 8 and 9.

2. A humanized antibody, or a derived compound or functional fragment of same, according to claim 1, characterized in that it comprises a heavy chain variable region of sequence selected from the group consisting of SEQ ID Nos. 10, 11, 12, 13, 83, 85 or 87 and a light chain variable region of sequence selected from the group consisting of SEQ ID Nos. 14, 15, 16, 17, 18, 19, 20, 84, 86 or 88.

3. A humanized antibody, or a derived compound or functional fragment of same, according to claim 1, characterized in that it comprises a heavy chain of sequence selected from the group consisting of SEQ ID Nos. 21, 22, 23, 24, 89 or 91 and a light chain of sequence selected from the group consisting of SEQ ID Nos. 25, 26, 27, 28, 29, 30, 31, 90 or 92.

4. A humanized antibody, or a derived compound or functional fragment of same, according to claim 1, selected from the group consisting of:

- humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain variable region of sequence SEQ ID No. 11, and a light chain variable region of sequence SEQ ID No. 16;
- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain of sequence SEQ ID No. 22, and a light chain of sequence SEQ ID No. 27;
- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain variable region of sequence SEQ ID No. 11, and a light chain variable region of sequence SEQ ID No. 17;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain of sequence SEQ ID No. 22, and a light chain of sequence SEQ ID No. 28;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain variable region of sequence SEQ ID No. 11, and a light chain variable region of sequence SEQ ID No. 18;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain of sequence SEQ ID No. 22, and a light chain of sequence SEQ ID No. 29;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain variable region of sequence SEQ ID No. 11, and a light chain variable region of sequence SEQ ID No. 19;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain of sequence SEQ ID No. 22, and a light chain of sequence SEQ ID No. 30;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain variable region of sequence SEQ ID No. 12, and a light chain variable region of sequence SEQ ID No. 14;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain of sequence SEQ ID No. 23, and a light chain of sequence SEQ ID No. 25;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain variable region of sequence SEQ ID No. 12, and a light chain variable region of sequence SEQ ID No. 15;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain of sequence SEQ ID No. 23, and a light chain of sequence SEQ ID No. 26;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain variable region of sequence SEQ ID No. 10, and a light chain variable region of sequence SEQ ID No. 14;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain of sequence SEQ ID No. 21, and a light chain of sequence SEQ ID No. 25;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain variable region of sequence SEQ ID No. 10, and a light chain variable region of sequence SEQ ID No. 88;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain of sequence SEQ ID No. 21, and a light chain of sequence SEQ ID No. 92;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain variable region of sequence SEQ ID No. 11, and a light chain variable region of sequence SEQ ID No. 88;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain of sequence SEQ ID No. 22, and a light chain of sequence SEQ ID No. 92;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain variable region of sequence SEQ ID No. 12, and a light chain variable region of sequence SEQ ID No. 88;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain of sequence SEQ ID No. 23, and a light chain of sequence SEQ ID No. 92;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain variable region of sequence SEQ ID No. 13, and a light chain variable region of sequence SEQ ID No. 88;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain of sequence SEQ ID No. 24, and a light chain of sequence SEQ ID No. 92;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain variable region of sequence SEQ ID No. 87, and a light chain variable region of sequence SEQ ID No. 14;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain of sequence SEQ ID No. 91, and a light chain of sequence SEQ ID No. 25;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain variable region of sequence SEQ ID No. 87, and a light chain variable region of sequence SEQ ID No. 15;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain of sequence SEQ ID No. 91, and a light chain of sequence SEQ ID No. 26;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain variable region of sequence SEQ ID No. 87, and a light chain variable region of sequence SEQ ID No. 16;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain of sequence SEQ ID No. 91, and a light chain of sequence SEQ ID No. 27;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain variable region of sequence SEQ ID No. 87, and a light chain variable region of sequence SEQ ID No. 17;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain of sequence SEQ ID No. 91, and a light chain of sequence SEQ ID No. 28;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain variable region of sequence SEQ ID No. 87, and a light chain variable region of sequence SEQ ID No. 18;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain of sequence SEQ ID No. 91, and a light chain of sequence SEQ ID No. 29;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain variable region of sequence SEQ ID No. 87, and a light chain variable region of sequence SEQ ID No. 19;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain of sequence SEQ ID No. 91, and a light chain of sequence SEQ ID No. 30;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain variable region of sequence SEQ ID No. 87, and a light chain variable region of sequence SEQ ID No. 20;

- a humanized antibody, or a derived compound or functional fragment of same, characterized in that it comprises a heavy chain of sequence SEQ ID No. 91, and a light chain of sequence SEQ ID No. 31.

5. An isolated nucleic acid molecule characterized in that it is selected among the following nucleic acids:

a) a nucleic acid, DNA or RNA, coding for a humanized antibody, or for a derived compound or functional fragment of same, according to one of the claims 1 to 4;

b) a nucleic acid complementary to a nucleic acid as defined in a);

c) a nucleic acid of at least 18 nucleotides capable of hybridizing under highly stringent conditions with at least one of the 3 CDRs of a heavy chain comprising the nucleic acid sequences SEQ ID Nos. 38 to 41, 49 to 52, 93 or 95; and

d) a nucleic acid of at least 18 nucleotides capable of hybridizing under highly stringent conditions with at least one of the 3 CDRs of a light chain comprising the nucleic acid sequences SEQ ID Nos. 42 to 48, 53 to 59, 94 or 96.

6. An isolated nucleic acid molecule according to claim 5 comprising a nucleic acid sequence selected from the group consisting of:

- a nucleic acid sequence encoding a heavy chain variable region of a humanized antibody, said heavy chain variable region nucleotide sequence comprising a CDR-H1 nucleotide sequence of SEQ ID No. 32, a CDR-H2 nucleotide sequence of SEQ ID No. 33 and a CDR-H3 nucleotide sequence of SEQ ID No. 34;
- a nucleic acid sequence encoding a light chain variable region of a humanized antibody, said light chain variable region nucleotide sequence comprising a CDR-L1 nucleotide sequence of SEQ ID No. 35 or 60, a CDR-L2 nucleotide sequence of SEQ ID No. 36 or 61, and a CDR-L3 nucleotide sequence of SEQ ID No. 37 or 62; and
- a nucleic acid sequence encoding a nucleic acid sequence encoding a heavy chain variable region and a light chain variable region of a humanized antibody,

i) said heavy chain variable region nucleotide sequence comprising a CDR-H1 nucleotide sequence of SEQ ID No. 32, a CDR-H2 nucleotide sequence of SEQ ID No. 33 and a CDR-H3 nucleotide sequence of SEQ ID No. 34; and

ii) said light chain variable region nucleotide sequence comprising a CDR-L1 nucleotide sequence of SEQ ID No. 35 or 60, a CDR-L2 nucleotide sequence of SEQ ID No. 36 or 61, and a CDR-L3 nucleotide sequence of SEQ ID No. 37 or 62.

7. A vector composed of a nucleic acid according to any of the claims 5 and 6.

8. A host cell comprising a vector according to claim 7.

9. A transgenic animal, except for man, comprising a cell transformed by a vector according to claim 8.

10. A method for producing a humanized antibody, or a derived compound or functional fragment of same, characterized in that said method comprises the following steps:

- the culture in a medium of and the suitable culture conditions for a host cell according to claim 8; and

- the recovery of said antibody, or one of its functional fragments, thus produced from the culture medium or from said cultured cells.

11. A humanized antibody, or a derived compound or functional fragment of same, according to one of the claims 1 to 4, for use as a drug.

12. A composition comprising as an active ingredient a compound consisting of a humanized antibody, or a derived compound or functional fragment of same, according to one of the claims 1 to 4 and 11.

13. A composition according to claim 12, characterized in that it comprises, in addition, as a combination product for use in a simultaneous, separated or extended fashion, an anti-tumor antibody other that an antibody directed against CXCR4.

14. A composition according to one of the claims 12 or 13, characterized in that it comprises, in addition, as a combination or conjugation product for use in a simultaneous, separated or extended fashion, a cytotoxic/cytostatic agent, a cellular toxin and/or a radioisotope.

15. A composition according to one of the claims 12 to 13, for use as a drug.

16. A humanized antibody, or a derived compound or functional fragment of same, according to any of the claims 1 to 4 or 11, and/or of a composition according to any of the claims 16 to 18, for the prevention or treatment of cancer.

17. A humanized antibody, or a derived compound or functional fragment of same, and/or a composition according to claim 16, characterized in that said cancer is a cancer selected among prostate cancer, osteosarcoma, lung cancer, breast cancer, endometrial cancer, multiple myeloma, ovarian cancer, pancreatic cancer and colon cancer.

18. A process of detecting in vitro the presence and/or the location of a CXCR4 expressing tumor in a subject, wherein said process comprises the steps of:

(a) contacting a sample from the subject with a humanized antibody, or a derived compound or functional fragment of same, according to one of the claims 1 to 4 or 11; and

(b) detecting the binding of said antibody with the sample.

19. A kit comprising at least a humanized antibody, or a derived compound or functional fragment of same, according to one of the claims 1 to 4 or 11, said antibody being preferably labeled.