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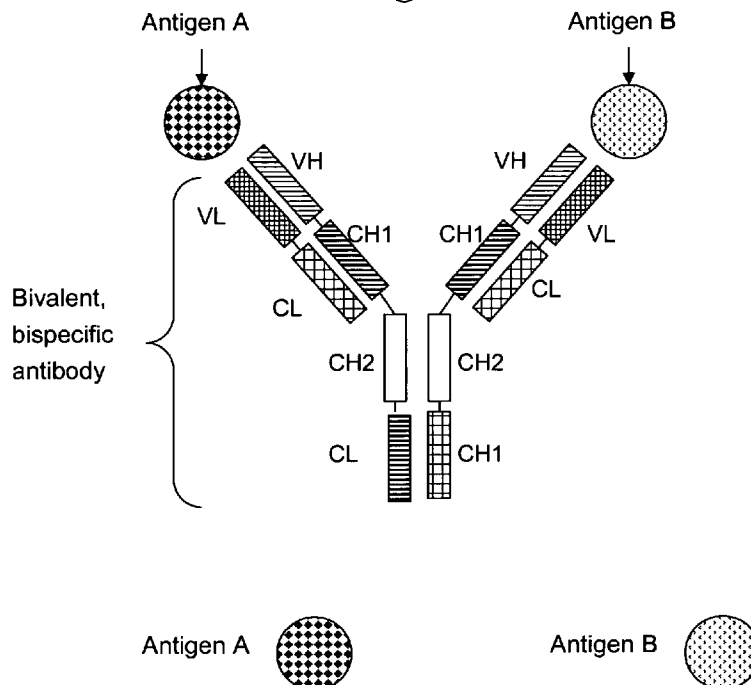
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Fig. 2



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(57) Abstract: The present invention relates to novel domain exchanged, bivalent, bispecific antibodies, their manufacture and use.

## Bivalent, bispecific antibodies

The present invention relates to novel bivalent, bispecific antibodies, their manufacture and use.

### Background of the Invention

5 Engineered proteins, such as bi- or multispecific antibodies capable of binding two or more antigens are known in the art. Such multispecific binding proteins can be generated using cell fusion, chemical conjugation, or recombinant DNA techniques.

10 A wide variety of recombinant bispecific antibody formats have been developed in the recent past, e.g. tetravalent bispecific antibodies by fusion of, e.g. an IgG antibody format and single chain domains (see e.g. Coloma, M.J., et al., Nature Biotech 15 (1997) 159-163; WO 2001/077342; and Morrison, S.L., Nature Biotech 25 (2007) 1233-1234).

15 Also several other new formats wherein the antibody core structure (IgA, IgD, IgE, IgG or IgM) is no longer retained such as dia-, tria- or tetrabodies, minibodies, several single chain formats (scFv, Bis-scFv), which are capable of binding two or more antigens, have been developed (Holliger, P., et al., Nature Biotech 23 (2005) 1126-1136 2005; Fischer, N., Léger, O., Pathobiology 74 (2007) 3-14; Shen, J-, et al., Journal of Immunological Methods 318 (2007) 65-74; Wu, C., et al., Nature Biotech 25 (2007) 1290-1297).

20 All such formats use linkers either to fuse the antibody core (IgA, IgD, IgE, IgG or IgM) to a further binding protein (e.g. scFv) or to fuse e.g. two Fab fragments or scFv. (Fischer, N., Léger, O., Pathobiology 74 (2007) 3-14). While it is obvious that linkers have advantages for the engineering of bispecific antibodies, they may also cause problems in therapeutic settings. Indeed, these foreign peptides might elicit  
25 an immune response against the linker itself or the junction between the protein and the linker. Further more, the flexible nature of these peptides makes them more prone to proteolytic cleavage, potentially leading to poor antibody stability, aggregation and increased immunogenicity. In addition one may want to retain effector functions, such as e.g. complement-dependent cytotoxicity (CDC) or  
30 antibody dependent cellular cytotoxicity (ADCC), which are mediated through the

Fc receptor binding, by maintaining a high degree of similarity to naturally occurring.

Thus ideally, one should aim at developing bispecific antibodies that are very similar in general structure to naturally occurring antibodies (like IgA, IgD, IgE, IgG or IgM) with minimal deviation from human sequences.

In one approach bispecific antibodies that are very similar to natural antibodies have been produced using the quadroma technology (see Milstein, C., and Cuello, A.C., Nature 305 (1983) 537-40) based on the somatic fusion of two different hybridoma cell lines expressing murine monoclonal antibodies with the desired specificities of the bispecific antibody. Because of the random pairing of two different antibody heavy and light chains within the resulting hybrid-hybridoma (or quadroma) cell line, up to ten different antibody species are generated of which only one is the desired, functional bispecific antibody. Due to the presence of mispaired byproducts, and significantly reduced production yields, means sophisticated purification procedures are required (see e.g. Morrison, S.L., Nature Biotech 25 (2007) 1233-1234). In general the same problem of mispaired byproducts remains if recombinant expression techniques are used.

An approach to circumvent the problem of mispaired byproducts, which is known as 'knobs-into-holes' , aims at forcing the pairing of two different antibody heavy chains by introducing mutations into the CH3 domains to modify the contact interface. On one chain bulky amino acids were replaced by amino acids with short side chains to create a 'hole'. Conversely, amino acids with large side chains were introduced into the other CH3 domain, to create a 'knob'. By coexpressing these two heavy chains (and two identical light chains, which have to be appropriate for both heavy chains), high yields of heterodimer formation ('knob-hole') versus homodimer formation ('hole-hole' or 'knob-knob') was observed (Ridgway, J.B., Presta, L.G., Carter, P. and WO 96/027011). The percentage of heterodimer could be further increased by remodeling the interaction surfaces of the two CH3 domains using a phage display approach and the introduction of a disulfide bridge to stabilize the heterodimers (Merchant, A.M, et al., Nature Biotech 16 (1998) 677-681; Atwell, S., Ridgway, J.B., Wells, J.A., Carter, P., J., Mol Biol 270 (1997) 26-35). New approaches for the knobs-into-holes technology are described in e.g. in EP 1870459A1. Although this format appears very attractive, no data describing progression towards the clinic are currently available. One important constraint of this strategy is that the light chains of the two parent antibodies have to be identical

to prevent mispairing and formation of inactive molecules. Thus this technique is not appropriate for easily developing recombinant, bivalent, bispecific antibodies against two antigens starting from two antibodies against the first and the second antigen, as either the heavy chains of these antibodies an/or the identical light chains have to be optimized.

WO 99/37791 describes multipurpose antibody derivatives.

### Summary of the Invention

The invention relates to a bivalent, bispecific antibody, comprising:

- 10 a) the light chain and heavy chain of an antibody specifically binding to a first antigen,  
wherein the heavy chain domain CH3 is replaced by a constant heavy chain domain CH1;
- 15 b) the light chain and heavy chain of an antibody specifically binding to a second antigen,  
wherein the constant heavy chain domain CH3 is replaced by a constant light chain domain CL.

20 A further embodiment of the invention is a method for the preparation of an a bivalent, bispecific antibody according to the invention

comprising the steps of

- a) transforming a host cell with
  - 25 - vectors comprising nucleic acid molecules encoding the light chain and heavy chain of an antibody specifically binding to a first antigen,  
wherein the heavy chain domain CH3 is replaced by a constant heavy chain domain CH1;
  - vectors comprising nucleic acid molecules encoding the light chain and heavy chain of an antibody specifically binding to a second antigen,  
30 wherein the constant heavy chain domain CH3 is replaced by a constant light chain domain CL;

b) culturing the host cell under conditions that allow synthesis of said antibody molecule; and

c) recovering said antibody molecule from said culture.

A further embodiment of the invention is a host cell comprising

5 - vectors comprising nucleic acid molecules encoding the light chain and heavy chain of an antibody specifically binding to a first antigen, wherein the heavy chain domain CH3 is replaced by a constant heavy chain domain CH1; and

10 - vectors comprising nucleic acid molecules encoding the light chain and heavy chain of an antibody specifically binding to a second antigen, wherein the constant heavy chain domain CH3 is replaced by a constant light chain domain CL.

15 A further embodiment of the invention is a composition, preferably a pharmaceutical or a diagnostic composition of the antibody according to the invention.

A further embodiment of the invention is a pharmaceutical composition comprising an antibody according to the invention and at least one pharmaceutically acceptable excipient.

20 A further embodiment of the invention is a method for the treatment of a patient in need of therapy, characterized by administering to the patient a therapeutically effective amount of an antibody according to the invention.

### Detailed Description of the Invention

The invention relates to a bivalent, bispecific antibody, comprising:

25 a) the light chain and heavy chain of an antibody specifically binding to a first antigen, wherein the heavy chain domain CH3 is replaced by a constant heavy chain domain CH1;

30 b) the light chain and heavy chain of an antibody specifically binding to a second antigen,

wherein the constant heavy chain domain CH3 is replaced by a constant light chain domain CL.

Therefore said bivalent, bispecific antibody, comprises:

- 5           a) a first light chain and a first heavy chain of an antibody specifically binding to a first antigen, wherein the heavy chain domain CH3 is replaced by a constant heavy chain domain CH1;
- b) a second light chain and a second heavy chain of an antibody specifically binding to a second antigen, wherein the constant heavy chain domain
- 10           CH3 is replaced by a constant light chain domain CL.

The term "antibody" as used herein refers to whole, monoclonal antibodies. Such whole antibodies consist of two pairs of a "light chain" (LC) and a "heavy chain" (HC) (such light chain (LC) /heavy chain pairs are abbreviated herein as LC/HC).

15           The light chains and heavy chains of such antibodies are polypeptides consisting of several domains. In a whole antibody, each heavy chain comprises a heavy chain variable region (abbreviated herein as HCVR or VH) and a heavy chain constant region. The heavy chain constant region comprises the heavy chain constant domains CH1, CH2 and CH3 (antibody classes IgA, IgD, and IgG) and optionally

20           the heavy chain constant domain CH4 (antibody classes IgE and IgM). Each light chain comprises a light chain variable domain VL and a light chain constant domain CL. The structure of one naturally occurring whole antibody, the IgG antibody, is shown e.g. in Fig.1. The variable domains VH and VL can be further subdivided into regions of hypervariability, termed complementarity determining

25           regions (CDR), interspersed with regions that are more conserved, termed framework regions (FR). Each VH and VL is composed of three CDRs and four FRs, arranged from amino-terminus to carboxy-terminus in the following order: FR1, CDR1, FR2, CDR2, FR3, CDR3, FR4 ((Janeway, C.A., Jr. et al. (2001). Immunobiology., 5th ed., Garland Publishing; and Woof, J., Burton, D., Nat Rev

30           Immunol 4 (2004) 89-99). The two pairs of heavy chain and light chain (HC/LC) are capable of specifically binding to same antigen. Thus said whole antibody is a bivalent, monospecific antibody. Such "antibodies" include e.g. mouse antibodies, human antibodies, chimeric antibodies, humanized antibodies and genetically engineered antibodies (variant or mutant antibodies) as long as their characteristic

35           properties are retained. Especially preferred are human or humanized antibodies, especially as recombinant human or humanized antibodies.

There are five types of mammalian antibody heavy chains denoted by the Greek letters:  $\alpha$ ,  $\delta$ ,  $\epsilon$ ,  $\gamma$ , and  $\mu$  (Janeway, C.A., Jr., et al., (2001). Immunobiology., 5th ed., Garland Publishing). The type of heavy chain present defines the class of antibody; these chains are found in IgA, IgD, IgE, IgG, and IgM antibodies, respectively  
5 (Rhoades, R.A., Pflanzner RG (2002). Human Physiology, 4th ed., Thomson Learning). Distinct heavy chains differ in size and composition;  $\alpha$  and  $\gamma$  contain approximately 450 amino acids, while  $\mu$  and  $\epsilon$  have approximately 550 amino acids.

Each heavy chain has two regions, the constant region and the variable region. The constant region is identical in all antibodies of the same isotype, but differs in  
10 antibodies of different isotype. Heavy chains  $\gamma$ ,  $\alpha$  and  $\delta$  have a constant region composed of three constant domains CH1, CH2, and CH3 (in a line) , and a hinge region for added flexibility (Woof, J., Burton, D., Nat Rev Immunol 4 (2004) 89-99); heavy chains  $\mu$  and  $\epsilon$  have a constant region composed of four constant domains CH1, CH2, CH3, and CH4 (Janeway, C.A., Jr., et al., (2001).  
15 Immunobiology., 5th ed., Garland Publishing). The variable region of the heavy chain differs in antibodies produced by different B cells, but is the same for all antibodies produced by a single B cell or B cell clone. The variable region of each heavy chain is approximately 110 amino acids long and is composed of a single antibody domain.

20 In mammals there are only two types of light chains, which are called lambda ( $\lambda$ ) and kappa ( $\kappa$ ). A light chain has two successive domains: one constant domain CL and one variable domain VL. The approximate length of a light chain is 211 to 217 amino acids.

The terms "monoclonal antibody" or "monoclonal antibody composition" as used  
25 herein refer to a preparation of antibody molecules of a single amino acid composition.

The "antibodies" according to the invention can be of any class (e.g. IgA, IgD, IgE, IgG, and IgM, preferably IgG or IgE), or subclass (e.g., IgG1, IgG2, IgG3, IgG4, IgA1 and IgA2, preferably IgG1), whereby both antibodies, from which the bivalent  
30 bispecific antibody according to the invention is derived, are of the same subclass( e.g. IgG1, IgG4 and the like, preferably IgG1), preferably of the same allotype (e.g. Caucasian).

A "Fc part of an antibody" is a term well known to the skilled artisan and defined on the basis of papain cleavage of antibodies. The antibodies according to the invention contain as Fc part, preferably a Fc part derived from human origin and preferably all other parts of the human constant regions. The Fc part of an antibody is directly involved in complement activation, C1q binding, C3 activation and Fc receptor binding. While the influence of an antibody on the complement system is dependent on certain conditions, binding to C1q is caused by defined binding sites in the Fc part. Such binding sites are known in the state of the art and described e.g. by Lukas, T.J., et al., *J. Immunol.* 127 (1981) 2555-2560; Brunhouse, R., and Cebra, J.J., *Mol. Immunol.* 16 (1979) 907-917; Burton, D.R., et al., *Nature* 288 (1980) 338-344; Thommesen, J.E., et al., *Mol. Immunol.* 37 (2000) 995-1004; Idusogie, E.E., et al., *J. Immunol.* 164 (2000) 4178-4184; Hezareh, M., et al., *J. Virol.* 75 (2001) 12161-12168; Morgan, A., et al., *Immunology* 86 (1995) 319-324; and EP 0307 434. Such binding sites are e.g. L234, L235, D270, N297, E318, K320, K322, P331 and P329 (numbering according to EU index of Kabat, see below). Antibodies of subclass IgG1, IgG2 and IgG3 usually show complement activation, C1q binding and C3 activation, whereas IgG4 do not activate the complement system, do not bind C1q and do not activate C3. Preferably the Fc part is a human Fc part.

The term "chimeric antibody" refers to an antibody comprising a variable region, i.e., binding region, from one source or species and at least a portion of a constant region derived from a different source or species, usually prepared by recombinant DNA techniques. Chimeric antibodies comprising a murine variable region and a human constant region are preferred. Other preferred forms of "chimeric antibodies" encompassed by the present invention are those in which the constant region has been modified or changed from that of the original antibody to generate the properties according to the invention, especially in regard to C1q binding and/or Fc receptor (FcR) binding. Such chimeric antibodies are also referred to as "class-switched antibodies.". Chimeric antibodies are the product of expressed immunoglobulin genes comprising DNA segments encoding immunoglobulin variable regions and DNA segments encoding immunoglobulin constant regions. Methods for producing chimeric antibodies involve conventional recombinant DNA and gene transfection techniques are well known in the art. See, e.g., Morrison, S.L., et al., *Proc. Natl. Acad. Sci. USA* 81 (1984) 6851-6855; US 5,202,238 and US 5,204,244.



The term "humanized antibody" refers to antibodies in which the framework or "complementarity determining regions" (CDR) have been modified to comprise the CDR of an immunoglobulin of different specificity as compared to that of the parent immunoglobulin. In a preferred embodiment, a murine CDR is grafted into the framework region of a human antibody to prepare the "humanized antibody." See, e.g., Riechmann, L., et al., *Nature* 332 (1988) 323-327; and Neuberger, M.S., et al., *Nature* 314 (1985) 268-270. Particularly preferred CDRs correspond to those representing sequences recognizing the antigens noted above for chimeric antibodies. Other forms of "humanized antibodies" encompassed by the present invention are those in which the constant region has been additionally modified or changed from that of the original antibody to generate the properties according to the invention, especially in regard to C1q binding and/or Fc receptor (FcR) binding.

The term "human antibody", as used herein, is intended to include antibodies having variable and constant regions derived from human germ line immunoglobulin sequences. Human antibodies are well-known in the state of the art (van Dijk, M.A., and van de Winkel, J.G., *Curr. Opin. Chem. Biol.* 5 (2001) 368-374). Human antibodies can also be produced in transgenic animals (e.g., mice) that are capable, upon immunization, of producing a full repertoire or a selection of human antibodies in the absence of endogenous immunoglobulin production. Transfer of the human germ-line immunoglobulin gene array in such germ-line mutant mice will result in the production of human antibodies upon antigen challenge (see, e.g., Jakobovits, A., et al., *Proc. Natl. Acad. Sci. USA* 90 (1993) 2551-2555; Jakobovits, A., et al., *Nature* 362 (1993) 255-258; Bruggemann, M., et al., *Year Immunol.* 7 (1993) 33-40). Human antibodies can also be produced in phage display libraries (Hoogenboom, H.R., and Winter, G., *J. Mol. Biol.* 227 (1992) 381-388; Marks, J.D., et al., *J. Mol. Biol.* 222 (1991) 581-597). The techniques of Cole, et al., and Boerner, et al. are also available for the preparation of human monoclonal antibodies (Cole, et al., *Monoclonal Antibodies and Cancer Therapy*, Alan R. Liss, p. 77 (1985); and Boerner, P., et al., *J. Immunol.* 147 (1991) 86-95). As already mentioned for chimeric and humanized antibodies according to the invention the term "human antibody" as used herein also comprises such antibodies which are modified in the constant region to generate the properties according to the invention, especially in regard to C1q binding and/or FcR binding, e.g. by "class switching" i.e. change or mutation of Fc parts (e.g. from IgG1 to IgG4 and/or IgG1/IgG4 mutation.)

The term "recombinant human antibody", as used herein, is intended to include all human antibodies that are prepared, expressed, created or isolated by recombinant means, such as antibodies isolated from a host cell such as a NS0 or CHO cell or from an animal (e.g. a mouse) that is transgenic for human immunoglobulin genes or antibodies expressed using a recombinant expression vector transfected into a host cell. Such recombinant human antibodies have variable and constant regions in a rearranged form. The recombinant human antibodies according to the invention have been subjected to *in vivo* somatic hypermutation. Thus, the amino acid sequences of the VH and VL regions of the recombinant antibodies are sequences that, while derived from and related to human germ line VH and VL sequences, may not naturally exist within the human antibody germ line repertoire *in vivo*.

The "variable domain" (variable domain of a light chain (VL), variable region of a heavy chain (VH)) as used herein denotes each of the pair of light and heavy chains which is involved directly in binding the antibody to the antigen. The domains of variable human light and heavy chains have the same general structure and each domain comprises four framework (FR) regions whose sequences are widely conserved, connected by three "hypervariable regions" (or complementarity determining regions, CDRs). The framework regions adopt a  $\beta$ -sheet conformation and the CDRs may form loops connecting the  $\beta$ -sheet structure. The CDRs in each chain are held in their three-dimensional structure by the framework regions and form together with the CDRs from the other chain the antigen binding site. The antibody heavy and light chain CDR3 regions play a particularly important role in the binding specificity/affinity of the antibodies according to the invention and therefore provide a further object of the invention.

The terms "hypervariable region" or "antigen-binding portion of an antibody" when used herein refer to the amino acid residues of an antibody which are responsible for antigen-binding. The hypervariable region comprises amino acid residues from the "complementarity determining regions" or "CDRs". "Framework" or "FR" regions are those variable domain regions other than the hypervariable region residues as herein defined. Therefore, the light and heavy chains of an antibody comprise from N- to C-terminus the domains FR1, CDR1, FR2, CDR2, FR3, CDR3, and FR4. CDRs on each chain are separated by such framework amino acids. Especially, CDR3 of the heavy chain is the region which contributes most to antigen binding. CDR and FR regions are determined according to the standard definition

of Kabat et al., Sequences of Proteins of Immunological Interest, 5th ed., Public Health Service, National Institutes of Health, Bethesda, MD (1991).

5 The "constant domains" of the heavy chain and of the light chain are not involved directly in binding of an antibody to an antigen, but exhibit various effector functions. Depending on the amino acid sequence of the constant region of their heavy chains, antibodies or immunoglobulins are divided into the classes:

10 The term "bivalent, bispecific antibody" as used herein refers to an antibody as described above in which each of the two pairs of heavy chain and light chain (HC/LC) is specifically binding to a different antigen, i.e. the first heavy and the first light chain (originating from an antibody against a first antigen) are specifically binding together to a first antigen, and , the second heavy and the second light chain (originating from an antibody against a second antigen ) are specifically binding together to a second antigen (as depicted in Fig. 2); such bivalent, bispecific antibodies are capable of specifically binding to two different antigens at the same time, and not to more than two antigens, in contrary to, on the one hand a monospecific antibody capable of binding only to one antigen, and on the other hand e.g. a tetravalent, tetraspecific antibody which can bind to four antigen molecules at the same time.

20 According to the invention, the ratio of a desired bivalent, bispecific antibody compared to undesired side products can be improved by the replacement of the CH3 domains of both heavy chains. Thus the heavy chain of an antibody specifically binding to a first antigen and the heavy chain of an antibody specifically binding to a second antigen are altered by the following replacement:

- 25 - First heavy chain: replacement of the constant heavy chain domain CH3 by the constant heavy chain domain CH1 of said antibody specifically binding to a first antigen , and
- Second heavy chain: replacement of the constant heavy chain domain CH3 by the constant light chain domain CL of said antibody specifically binding to a second antigen.

30

Thus the resulting bivalent, bispecific antibodies are artificial antibodies which comprise

- a) the light chain and heavy chain of an antibody specifically binding to a first antigen, wherein said heavy chain contains (at the position of

the constant heavy chain domain CH3) a (second) constant heavy chain domain CH1 instead of the constant heavy chain domain CH3, and

- 5 b) the light chain and heavy chain of an antibody specifically binding to a second antigen, wherein said heavy chain contains a constant light chain domain CL instead of a constant heavy chain domain CH3.

10 The constant heavy chain domain CH1 by which the heavy chain domain CH3 is replaced can be of any Ig class (e.g. IgA, IgD, IgE, IgG, and IgM), or subclass (e.g., IgG1, IgG2, IgG3, IgG4, IgA1 and IgA2).

The constant light chain domain CL by which the heavy chain domain CH3 is replaced can be of the lambda ( $\lambda$ ) or kappa ( $\kappa$ ) type, preferably the kappa ( $\kappa$ ) type.

15 In an additional aspect of the invention such improved ratio of a desired bivalent, bispecific antibody compared to undesired side products can be further improved by the additional alteration of the light chain and heavy chain of said antibody specifically binding to a second antigen according to one of the following three alternatives:

20

A) First alternative (see Fig. 3):

The light chain and heavy chain of either said first antibody specifically binding to a first antigen or said second antibody specifically binding the second antigen is altered by the replacement of the variable domains VL and VH by each other.

25

or

B) Second alternative (see Figure 4):

The light chain and heavy chain of either said first antibody specifically binding to a first antigen or said second antibody specifically binding the second antigen is altered by the replacement of the constant domains CL and CH1 by each other.

30

or

C) Third alternative (see Figure 5):

The light chain and heavy chain of either said first antibody specifically binding to a first antigen or said second antibody specifically binding the second antigen is altered

- 5           by the replacement of the variable domains VL and VH by each other,  
          and  
          by the replacement of the variable domains CL and CH1 by each other.

Thus one preferred embodiment of the invention is a bivalent, bispecific antibody, comprising:

- 10           a) the light chain and heavy chain of an antibody specifically binding to a first antigen,  
          wherein the heavy chain domain CH3 is replaced by a constant heavy chain domain CH1;
- 15           b) the light chain and heavy chain of an antibody specifically binding to a second antigen,  
          wherein the constant heavy chain domain CH3 is replaced by a constant light chain domain CL.
- 20           and wherein optionally the light chain and heavy chain of either said first antibody specifically binding to a first antigen or said second antibody specifically binding the second antigen is altered  
          by the replacement of the variable domains VL and VH by each other,  
          and/or
- 25           by the replacement of the variable domains CL and CH1 by each other.

The terms "antigen" or "antigen molecule" as used herein are used interchangeable and refer to all molecules that can be specifically bound by an antibody. The bivalent, bispecific antibody is specifically binding to a first antigen and a second distinct antigen. The term "antigens" as used herein include e.g. proteins, different  
30           epitopes on proteins (as different antigens within the meaning of the invention), and polysaccharides. This mainly includes parts (coats, capsules, cell walls, flagella, fimbriae, and toxins) of bacteria, viruses, and other microorganisms. Lipids and nucleic acids are antigenic only when combined with proteins and polysaccharides. Non-microbial exogenous (non-self) antigens can include pollen, egg white, and  
35           proteins from transplanted tissues and organs or on the surface of transfused blood cells. Preferably the antigen is selected from the group consisting of cytokines, cell

surface proteins, enzymes and receptors cytokines, cell surface proteins, enzymes and receptors.

5 Tumor antigens are those antigens that are presented by MHC I or MHC II molecules on the surface of tumor cells. These antigens can sometimes be presented by tumor cells and never by the normal ones. In this case, they are called tumor-specific antigens (TSAs) and typically result from a tumor specific mutation. More  
10 common are antigens that are presented by tumor cells and normal cells, and they are called tumor-associated antigens (TAAs). Cytotoxic T lymphocytes that recognized these antigens may be able to destroy the tumor cells before they proliferate or metastasize. Tumor antigens can also be on the surface of the tumor in the form of, for example, a mutated receptor, in which case they will be recognized by B cells.

15 In one preferred embodiment at least one of the two different antigens (first and second antigen) , to which the bivalent, bispecific antibody specifically binds to, is a tumor antigen.

In another preferred embodiment both of the two different antigens (first and second antigen), to which the bivalent, bispecific antibody specifically binds to, are tumor antigens; in this case the first and second antigen can also be two different epitopes at the same tumor specific protein.

20 In another preferred embodiment one of the two different antigens (first and second antigen), to which the bivalent, bispecific antibody specifically binds to, is a tumor antigen and the other is an effector cell antigen, as e.g. an T-Cell receptor, CD3, CD16 and the like.

25 In another preferred embodiment one of the two different antigens (first and second antigen), to which the bivalent, bispecific antibody specifically binds to, is a tumor antigen and the other is an anti-cancer substance such as a toxin or a kinase inhibitor.

30 As used herein, "specifically binding" or "binds specifically to" refers to an antibody specifically binding an antigen. Preferably the binding affinity of the antibody specifically binding this antigen is of KD-value of  $10^{-9}$  mol/l or lower (e.g.  $10^{-10}$  mol/l), preferably with a KD-value of  $10^{-10}$  mol/l or lower (e.g.  $10^{-12}$  mol/l). The binding affinity is determined with a standard binding assay, such as surface plasmon resonance technique (Biacore®).

The term "epitope" includes any polypeptide determinant capable of specific binding to an antibody. In certain embodiments, epitope determinant include chemically active surface groupings of molecules such as amino acids, sugar side chains, phosphoryl, or sulfonyl, and, in certain embodiments, may have specific three dimensional structural characteristics, and or specific charge characteristics. An epitope is a region of an antigen that is bound by an antibody. In certain embodiments, an antibody is said to specifically bind an antigen when it preferentially recognizes its target antigen in a complex mixture of proteins and/or macromolecules.

10 An further embodiment of the invention is a method for the preparation of a bivalent, bispecific antibody according to the invention

comprising

a) transforming a host cell with

15 - vectors comprising nucleic acid molecules encoding the light chain and heavy chain of an antibody specifically binding to a first antigen, wherein the heavy chain domain CH3 is replaced by a constant heavy chain domain CH1;

20 - vectors comprising nucleic acid molecules encoding the light chain and heavy chain of an antibody specifically binding to a second antigen, wherein the constant heavy chain domain CH3 is replaced by a constant light chain domain CL;

b) culturing the host cell under conditions that allow synthesis of said antibody molecule; and

c) recovering said antibody molecule from said culture.

25 In general there are two vectors encoding the light chain and heavy chain of said antibody specifically binding to a first antigen, and further two vectors encoding the light chain and heavy chain of said antibody specifically binding to a second antigen. One of the two vectors is encoding the respective light chain and the other of the two vectors is encoding the respective heavy chain. However in an alternative method for the preparation of a bivalent, bispecific antibody according to the invention, only one first vector encoding the light chain and heavy chain of the antibody specifically binding to a first antigen and only one second vector encoding

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the light chain and heavy chain of the antibody specifically binding to a second antigen can be used for transforming the host cell.

The invention encompasses a method for the preparation of the antibodies comprising culturing the corresponding host cells under conditions that allow  
5 synthesis of said antibody molecules and recovering said antibodies from said culture, e.g. by expressing

-a first nucleic acid sequence encoding the light chain of an antibody specifically binding to a first antigen;

10 -a second nucleic acid sequence encoding the heavy chain of said antibody specifically binding to a first antigen, wherein the heavy chain domain CH3 is replaced by a constant heavy chain domain CH1;

-a third nucleic acid sequence encoding the light chain of an antibody specifically binding to a second antigen; and

15 -a fourth nucleic acid sequence encoding the heavy chain of said antibody specifically binding to a second antigen, wherein the constant heavy chain domain CH3 is replaced by a constant light chain domain CL.

A further embodiment of the invention is a host cell comprising

20 - vectors comprising nucleic acid molecules encoding the light chain and heavy chain of an antibody specifically binding to a first antigen, wherein the heavy chain domain CH3 is replaced by a constant heavy chain domain CH1; and

25 - vectors comprising nucleic acid molecules encoding the light chain and heavy chain of an antibody specifically binding to a second antigen, wherein the constant heavy chain domain CH3 is replaced by a constant light chain domain CL.

A further embodiment of the invention is a host cell comprising

30 a) a vector comprising a nucleic acid molecule encoding the light chain and a vector comprising a nucleic acid molecule encoding the heavy chain, of an antibody specifically binding to a first antigen, wherein the heavy chain domain CH3 is replaced by a constant heavy chain domain CH1; and



b) a vector comprising a nucleic acid molecule encoding the light chain and a vector comprising a nucleic acid molecule encoding the heavy chain, of an antibody specifically binding to a second antigen, wherein the constant heavy chain domain CH3 is replaced by a constant light chain domain CL.

5 A further embodiment of the invention is a composition, preferably a pharmaceutical or a diagnostic composition of the bivalent, bispecific antibody according to the invention.

A further embodiment of the invention is a pharmaceutical composition comprising a bivalent, bispecific antibody according to the invention and at least  
10 one pharmaceutically acceptable excipient.

A further embodiment of the invention is a method for the treatment of a patient in need of therapy, characterized by administering to the patient a therapeutically effective amount of a bivalent, bispecific antibody according to the invention.

15 The term "nucleic acid or nucleic acid molecule", as used herein, is intended to include DNA molecules and RNA molecules. A nucleic acid molecule may be single-stranded or double-stranded, but preferably is double-stranded DNA.

As used herein, the expressions "cell," "cell line," and "cell culture" are used interchangeably and all such designations include progeny. Thus, the words "transformants" and "transformed cells" include the primary subject cell and  
20 cultures derived therefrom without regard for the number of transfers. It is also understood that all progeny may not be precisely identical in DNA content, due to deliberate or inadvertent mutations. Variant progeny that have the same function or biological activity as screened for in the originally transformed cell are included. Where distinct designations are intended, it will be clear from the context.

25 The term "transformation" as used herein refers to process of transfer of a vectors/nucleic acid into a host cell. If cells without formidable cell wall barriers are used as host cells, transfection is carried out e.g. by the calcium phosphate precipitation method as described by Graham, F.L., and van der Eb, A., J. Virology 52 (1978) 546-467. However, other methods for introducing DNA into cells such as  
30 by nuclear injection or by protoplast fusion may also be used. If prokaryotic cells or cells which contain substantial cell wall constructions are used, e.g. one method of transfection is calcium treatment using calcium chloride as described by Cohen, S., N, et al., PNAS. 69 (1972) 2110-2114.

Recombinant production of antibodies using transformation is well-known in the state of the art and described, for example, in the review articles of Makrides, S.C., Protein Expr. Purif. 17 (1999) 183-202; Geisse, S., et al., Protein Expr. Purif. 8 (1996) 271-282; Kaufman, R.J., Mol. Biotechnol. 16 (2000) 151-161; Werner, R.G., et al., Arzneimittelforschung 48 (1998) 870-880 as well as in US 6,331,415 and US 4,816,567.

As used herein, "expression" refers to the process by which a nucleic acid is transcribed into mRNA and/or to the process by which the transcribed mRNA (also referred to as transcript) is subsequently being translated into peptides, polypeptides, or proteins. The transcripts and the encoded polypeptides are collectively referred to as gene product. If the polynucleotide is derived from genomic DNA, expression in a eukaryotic cell may include splicing of the mRNA.

A "vector" is a nucleic acid molecule, in particular self-replicating, which transfers an inserted nucleic acid molecule into and/or between host cells. The term includes vectors that function primarily for insertion of DNA or RNA into a cell (e.g., chromosomal integration), replication of vectors that function primarily for the replication of DNA or RNA, and expression vectors that function for transcription and/or translation of the DNA or RNA. Also included are vectors that provide more than one of the functions as described.

An "expression vector" is a polynucleotide which, when introduced into an appropriate host cell, can be transcribed and translated into a polypeptide. An "expression system" usually refers to a suitable host cell comprised of an expression vector that can function to yield a desired expression product.

The bivalent, bispecific antibodies according to the invention are preferably produced by recombinant means. Such methods are widely known in the state of the art and comprise protein expression in prokaryotic and eukaryotic cells with subsequent isolation of the antibody polypeptide and usually purification to a pharmaceutically acceptable purity. For the protein expression, nucleic acids encoding light and heavy chains or fragments thereof are inserted into expression vectors by standard methods. Expression is performed in appropriate prokaryotic or eukaryotic host cells like CHO cells, NS0 cells, SP2/0 cells, HEK293 cells, COS cells, yeast, or E.coli cells, and the antibody is recovered from the cells (supernatant or cells after lysis). The bivalent, bispecific antibodies may be present in whole cells, in a cell lysate, or in a partially purified or substantially pure form. Purification is

performed in order to eliminate other cellular components or other contaminants, e.g. other cellular nucleic acids or proteins, by standard techniques, including alkaline/SDS treatment, column chromatography and others well known in the art. See Ausubel, F., et al., ed., *Current Protocols in Molecular Biology*, Greene Publishing and Wiley Interscience, New York (1987).

Expression in NS0 cells is described by, e.g., Barnes, L.M., et al., *Cytotechnology* 32 (2000) 109-123; and Barnes, L.M., et al., *Biotech. Bioeng.* 73 (2001) 261-270. Transient expression is described by, e.g., Durocher, Y., et al., *Nucl. Acids. Res.* 30 (2002) E9. Cloning of variable domains is described by Orlandi, R., et al., *Proc. Natl. Acad. Sci. USA* 86 (1989) 3833-3837; Carter, P., et al., *Proc. Natl. Acad. Sci. USA* 89 (1992) 4285-4289; and Norderhaug, L., et al., *J. Immunol. Methods* 204 (1997) 77-87. A preferred transient expression system (HEK 293) is described by Schlaeger, E.-J., and Christensen, K., in *Cytotechnology* 30 (1999) 71-83 and by Schlaeger, E.-J., in *J. Immunol. Methods* 194 (1996) 191-199.

The control sequences that are suitable for prokaryotes, for example, include a promoter, optionally an operator sequence, and a ribosome binding site. Eukaryotic cells are known to utilize promoters, enhancers and polyadenylation signals.

Nucleic acid is "operably linked" when it is placed into a functional relationship with another nucleic acid sequence. For example, DNA for a presequence or secretory leader is operably linked to DNA for a polypeptide if it is expressed as a preprotein that participates in the secretion of the polypeptide; a promoter or enhancer is operably linked to a coding sequence if it affects the transcription of the sequence; or a ribosome binding site is operably linked to a coding sequence if it is positioned so as to facilitate translation. Generally, "operably linked" means that the DNA sequences being linked are contiguous, and, in the case of a secretory leader, contiguous and in reading frame. However, enhancers do not have to be contiguous. Linking is accomplished by ligation at convenient restriction sites. If such sites do not exist, the synthetic oligonucleotide adaptors or linkers are used in accordance with conventional practice.

The bivalent, bispecific antibodies are suitably separated from the culture medium by conventional immunoglobulin purification procedures such as, for example, protein A-Sepharose, hydroxylapatite chromatography, gel electrophoresis, dialysis, or affinity chromatography. DNA and RNA encoding the monoclonal antibodies is

readily isolated and sequenced using conventional procedures. The hybridoma cells can serve as a source of such DNA and RNA. Once isolated, the DNA may be inserted into expression vectors, which are then transfected into host cells such as HEK 293 cells, CHO cells, or myeloma cells that do not otherwise produce immunoglobulin protein, to obtain the synthesis of recombinant monoclonal antibodies in the host cells.

Amino acid sequence variants (or mutants) of the bivalent, bispecific antibody are prepared by introducing appropriate nucleotide changes into the antibody DNA, or by nucleotide synthesis. Such modifications can be performed, however, only in a very limited range, e.g. as described above. For example, the modifications do not alter the above mentioned antibody characteristics such as the IgG isotype and antigen binding, but may improve the yield of the recombinant production, protein stability or facilitate the purification.

The following examples, sequence listing and figures are provided to aid the understanding of the present invention, the true scope of which is set forth in the appended claims. It is understood that modifications can be made in the procedures set forth without departing from the spirit of the invention.

### Sequence Listing

SEQ ID NO: 1 amino acid sequence of wild type <IGF-1R> antibody heavy chain

SEQ ID NO: 2 amino acid sequence of wild type <IGF-1R> antibody light chain

SEQ ID NO: 3 amino acid sequence of <IGF-1R> HC# antibody heavy chain#, wherein the heavy chain domain CH3 is replaced by a constant heavy chain domain CH1

SEQ ID NO: 4 amino acid sequence of wild type Angiopoietin-2 <ANGPT2> antibody heavy chain

SEQ ID NO: 5 amino acid sequence of wild type Angiopoietin-2 <ANGPT2> antibody light chain

SEQ ID NO: 6 amino acid sequence of the heavy chain\* (HC\*) of <ANGPT2> VL-VH/CL-CH1 exchange antibody, wherein the heavy chain domain VH is replaced by the light chain domain VL, and the heavy chain domain CH1 is replaced by the light chain domain CL based on SEQ ID NO: 4 and SEQ ID NO: 5.

- 5 SEQ ID NO: 7 amino acid sequence of the light chain\* (LC\*) of <ANGPT2> VL-VH/CL-CH1 exchange antibody, wherein the light chain domain VL is replaced by the heavy chain domain VH, and the light chain domain CL is replaced by the heavy chain domain CH1 based on SEQ ID NO: 4 and SEQ ID NO: 5..
- 10 SEQ ID NO: 8 amino acid sequence of VL-VH/CL-CH1 exchange <ANGPT2> HC## antibody heavy chain ##, wherein the heavy chain domain VH is replaced by the light chain domain VL, and the heavy chain domain CH1 is replaced by the light chain domain CL and wherein the constant heavy chain domain CH3 is replaced by a kappa constant light chain domain CL without a C-terminal Cysteine residue (including leader sequence)
- 15 SEQ ID NO: 9 amino acid sequence of VL-VH/CL-CH1 exchange <ANGPT2> HC## antibody heavy chain ##, wherein the heavy chain domain VH is replaced by the light chain domain VL, and the heavy chain domain CH1 is replaced by the light chain domain CL and wherein the constant heavy chain domain CH3 is replaced by a kappa constant light chain domain CL with a C-terminal Cysteine residue (including leader sequence); sequence corresponds to SEQ ID NO: 8
- 20

### Description of the Figures

- 25 **Figure 1** Schematic figure of IgG, a naturally occurring whole antibody specific for one antigen with two pairs of heavy and light chain which comprise variable and constant domains in a typical order.
- 30 **Figure 2** Schematic figure of a bivalent, bispecific antibody, comprising: a) the light chain and heavy chain of an antibody specifically binding to a first antigen, wherein the heavy chain domain CH3 is replaced by a constant heavy chain domain CH1; b) the light chain and heavy chain of an antibody specifically binding to a second antigen, wherein the constant heavy chain domain CH3 is replaced by a constant light chain domain CL.

**Figure 3** Schematic figures of a bivalent, bispecific antibody, comprising:  
a) the light chain and heavy chain of an antibody specifically binding to a first antigen, wherein the heavy chain domain CH3 is replaced by a constant heavy chain domain CH1; b) the light chain and heavy chain of an antibody specifically binding to a second antigen, wherein the constant heavy chain domain CH3 is replaced by a constant light chain domain CL and wherein the light chain and heavy chain of either said first antibody specifically binding to a first antigen or said second antibody specifically binding the second antigen is altered by the replacement of the variable domains VL and VH by each other.

**Figure 4** Schematic figures of a bivalent, bispecific antibody, comprising:  
a) the light chain and heavy chain of an antibody specifically binding to a first antigen, wherein the heavy chain domain CH3 is replaced by a constant heavy chain domain CH1; b) the light chain and heavy chain of an antibody specifically binding to a second antigen, wherein the constant heavy chain domain CH3 is replaced by a constant light chain domain CL and wherein the light chain and heavy chain of either said first antibody specifically binding to a first antigen or said second antibody specifically binding the second antigen is altered by the replacement of the variable domains VL and VH by each other.

**Figure 5** Schematic figures of a bivalent, bispecific antibody, comprising:  
a) the light chain and heavy chain of an antibody specifically binding to a first antigen, wherein the heavy chain domain CH3 is replaced by a constant heavy chain domain CH1; b) the light chain and heavy chain of an antibody specifically binding to a second antigen, wherein the constant heavy chain domain CH3 is replaced by a constant light chain domain CL and wherein the light chain and heavy chain of either said first antibody specifically binding to a first antigen or said second antibody specifically binding the second antigen is altered by the replacement of the variable domains VL and VH by each other, and by the replacement of the variable domains VL and VH by each other.

- Figure 6 Protein sequence scheme of CH1-CL for CH3-CH3 exchange <IGF-1R> HC#
- Figure 7 Protein sequence scheme of CH1-CL for CH3-CH3 exchange <ANGPT2> HC## (with a kappa constant light chain domain CL)
- 5
- Figure 8 Plasmid maps of CH1-Ck for CH3-CH3 exchange <IGF-1R> HC# expression vector pUC-HC#-IGF-1R and the respective pUC <IGF-1R> LC expression vector pUC-LC-IGF-1R and of CH1-Ck for CH3-CH3 exchange <ANGPT2> VL-VH/CL-CH1 exchange HC## expression vector pUC-HC##-ANGPT2 and the respective <ANGPT2> VL-VH/CL-CH1 exchange LC expression vector pUC-LC##-ANGPT2
- 10
- Figure 9 SDS-PAGE of co-expression of plasmids pUC-HC#-IGF-1R and pUC-HC##-ANGPT2 together with the respective light chain vectors for the <IGF-1R> wildtype light chain (SEQ ID NO: 2) and the VL-VH/CL-CH1 exchange <ANGPT2> light chain (SEQ ID NO: 8) using the HEK293-F system.
- 15
- Figure 10 Assay principle of cellular FACS IGF-1R-ANGPT2 bridging assay on I24 IGF-1R expressing cells to detect the presence of functional bispecific <ANGPT2-IGF-1R> VL-VH exchange antibody
- 20

### Examples

#### 25 Materials & general methods

General information regarding the nucleotide sequences of human immunoglobulins light and heavy chains is given in: Kabat, E.A., et al., Sequences of Proteins of Immunological Interest, 5th ed., Public Health Service, National Institutes of Health, Bethesda, MD (1991). Amino acids of antibody chains are numbered and referred to according to EU numbering (Edelman, G.M., et al., Proc. Natl. Acad. Sci. USA 63 (1969) 78-85; Kabat, E.A., et al., Sequences of Proteins of

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Immunological Interest, 5th ed., Public Health Service, National Institutes of Health, Bethesda, MD, (1991)).

### **Recombinant DNA techniques**

5 Standard methods were used to manipulate DNA as described in Sambrook, J. et al., Molecular cloning: A laboratory manual; Cold Spring Harbor Laboratory Press, Cold Spring Harbor, New York, 1989. The molecular biological reagents were used according to the manufacturer's instructions.

### **Gene synthesis**

10 Desired gene segments were prepared from oligonucleotides made by chemical synthesis. The 600 - 1800 bp long gene segments, which are flanked by singular restriction endonuclease cleavage sites, were assembled by annealing and ligation of oligonucleotides including PCR amplification and subsequently cloned via the indicated restriction sites e.g. KpnI/ SacI or AscI/PacI into a pPCRScrip (Stratagene) based pGA4 cloning vector. The DNA sequences of the subcloned gene  
15 fragments were confirmed by DNA sequencing. Gene synthesis fragments were ordered according to given specifications at Geneart (Regensburg, Germany).

### **DNA sequence determination**

20 DNA sequences were determined by double strand sequencing performed at MediGenomix GmbH (Martinsried, Germany) or Sequiserve GmbH (Vaterstetten, Germany).

### **DNA and protein sequence analysis and sequence data management**

25 The GCG's (Genetics Computer Group, Madison, Wisconsin) software package version 10.2 and Infomax's Vector NT1 Advance suite version 8.0 was used for sequence creation, mapping, analysis, annotation and illustration. Expression vectors

For the expression of the described antibodies variants of expression plasmids for transient expression (e.g. in HEK293 EBNA or HEK293-F) cells based either on a cDNA organization with a CMV-Intron A promoter or on a genomic organization with a CMV promoter were applied.

30 Beside the antibody expression cassette the vectors contained:



- 24 -

- an origin of replication which allows replication of this plasmid in *E. coli*, and
- a  $\beta$ -lactamase gene which confers ampicillin resistance in *E. coli*.

The transcription unit of the antibody gene is composed of the following elements:

- unique restriction site(s) at the 5' end
- 5 - the immediate early enhancer and promoter from the human cytomegalovirus,
- followed by the Intron A sequence in the case of the cDNA organization,
- a 5'-untranslated region of a human antibody gene,
- a immunoglobulin heavy chain signal sequence,
- the human antibody chain (wildtype or with domain exchange) either as cDNA or
- 10 as genomic organization with an the immunoglobulin exon-intron organization
- a 3' untranslated region with a polyadenylation signal sequence, and
- unique restriction site(s) at the 3' end.

The fusion genes comprising the described antibody chains as described below were generated by PCR and/or gene synthesis and assembled with known recombinant

15 methods and techniques by connection of the according nucleic acid segments e.g. using unique restriction sites in the respective vectors. The subcloned nucleic acid sequences were verified by DNA sequencing. For transient transfections larger quantities of the plasmids were prepared by plasmid preparation from transformed *E. coli* cultures (Nucleobond AX, Macherey-Nagel).

## 20 Cell culture techniques

Standard cell culture techniques were used as described in Current Protocols in Cell Biology (2000), Bonifacino, J.S., Dasso, M., Harford, J.B., Lippincott-Schwartz, J. and Yamada, K.M. (eds.), John Wiley & Sons, Inc.

Bispecific antibodies were expressed by transient co-transfection of the respective

25 expression plasmids in adherently growing HEK293-EBNA or in HEK29-F cells growing in suspension as described below.

### Transient transfections in HEK293-EBNA system

Bispecific antibodies were expressed by transient co-transfection of the respective expression plasmids (e.g. encoding the heavy and modified heavy chain, as well as the corresponding light and modified light chain) in adherently growing HEK293-EBNA cells (human embryonic kidney cell line 293 expressing Epstein-Barr-Virus nuclear antigen; American type culture collection deposit number ATCC # CRL-10852, Lot. 959 218) cultivated in DMEM (Dulbecco's modified Eagle's medium, Gibco) supplemented with 10% Ultra Low IgG FCS (fetal calf serum, Gibco), 2 mM L-Glutamine (Gibco), and 250  $\mu\text{g}/\text{ml}$  Geneticin (Gibco). For transfection FuGENE™ 6 Transfection Reagent (Roche Molecular Biochemicals) was used in a ratio of FuGENE™ reagent ( $\mu\text{l}$ ) to DNA ( $\mu\text{g}$ ) of 4:1 (ranging from 3:1 to 6:1). Proteins were expressed from the respective plasmids using a molar ratio of (modified and wildtype) light chain and heavy chain encoding plasmids of 1:1 (equimolar) ranging from 1:2 to 2:1, respectively. Cells were feeded at day 3 with L-Glutamine ad 4 mM, Glucose [Sigma] and NAA [Gibco]. Bispecific antibody containing cell culture supernatants were harvested from day 5 to 11 after transfection by centrifugation and stored at  $-20^{\circ}\text{C}$ . General information regarding the recombinant expression of human immunoglobulins in e.g. HEK293 cells is given in: Meissner, P. et al., *Biotechnol. Bioeng.* 75 (2001) 197-203.

### Transient transfections in HEK293-F system

Bispecific antibodies were generated by transient transfection of the respective plasmids (e.g. encoding the heavy and modified heavy chain, as well as the corresponding light and modified light chain) using the HEK293-F system (Invitrogen) according to the manufacturer's instruction. Briefly, HEK293-F cells (Invitrogen) growing in suspension either in a shake flask or in a stirred fermenter in serumfree FreeStyle 293 expression medium (Invitrogen) were transfected with a mix of the four expression plasmids and 293fectin or fectin (Invitrogen). For 2 L shake flask (Corning) HEK293-F cells were seeded at a density of  $1.0\text{E}^6$  cells/mL in 600 mL and incubated at 120 rpm, 8%  $\text{CO}_2$ . The day after the cells were transfected at a cell density of ca.  $1.5\text{E}^6$  cells/mL with ca. 42 mL mix of A) 20 mL Opti-MEM (Invitrogen) with 600  $\mu\text{g}$  total plasmid DNA (1  $\mu\text{g}/\text{mL}$ ) encoding the heavy or modified heavy chain, respectively and the corresponding light chain in an equimolar ratio and B) 20 ml Opti-MEM + 1.2 mL 293 fectin or fectin (2  $\mu\text{l}/\text{mL}$ ).

According to the glucose consumption glucose solution was added during the course of the fermentation. The supernatant containing the secreted antibody was harvested after 5-10 days and antibodies were either directly purified from the supernatant or the supernatant was frozen and stored.

5

### Protein determination

The protein concentration of purified antibodies and derivativess was determined by determining the optical density (OD) at 280 nm, using the molar extinction coefficient calculated on the basis of the amino acid sequence according to Pace, C.N., et. al., Protein Science, 1995, 4, 2411-1423.

10

### Antibody concentration determination in supernatants

The concentration of antibodies and derivatives in cell culture supernatants was estimated by immunoprecipitation with Protein A Agarose-beads (Roche). 60 µL Protein A Agarose beads are washed three times in TBS-NP40 (50 mM Tris, pH 7.5, 150 mM NaCl, 1% Nonidet-P40). Subsequently, 1 -15 mL cell culture supernatant were applied to the Protein A Agarose beads pre-equilibrated in TBS-NP40. After incubation for at 1 h at room temperature the beads were washed on an Ultrafree-MC-filter column (Amicon] once with 0.5 mL TBS-NP40, twice with 0.5 mL 2x phosphate buffered saline (2xPBS, Roche) and briefly four times with 0.5 mL 100 mM Na-citrate pH 5,0. Bound antibody was eluted by addition of 35 µl NuPAGE® LDS Sample Buffer (Invitrogen). Half of the sample was combined with NuPAGE® Sample Reducing Agent or left unreduced, respectively, and heated for 10 min at 70°C. Consequently, 5-30 µl were applied to an 4-12% NuPAGE® Bis-Tris SDS-PAGE (Invitrogen) (with MOPS buffer for non-reduced SDS-PAGE and MES buffer with NuPAGE® Antioxidant running buffer additive (Invitrogen) for reduced SDS-PAGE) and stained with Coomassie Blue.

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The concentration of antibodies and derivatives in cell culture supernatants was quantitatively measured by affinity HPLC chromatography. Briefly, cell culture supernatants containing antibodies and derivatives that bind to Protein A were applied to an Applied Biosystems Poros A/20 column in 200 mM KH<sub>2</sub>PO<sub>4</sub>, 100 mM sodium citrate, pH 7.4 and eluted from the matrix with 200 mM NaCl, 100 mM citric acid, pH 2,5 on an Agilent HPLC 1100 system. The eluted protein was

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quantified by UV absorbance and integration of peak areas. A purified standard IgG1 antibody served as a standard.

Alternatively, the concentration of antibodies and derivatives in cell culture supernatants was measured by Sandwich-IgG-ELISA. Briefly, StreptaWell High Bind Streptavidin A-96 well microtiter plates (Roche) were coated with 100  $\mu\text{L}/\text{well}$  biotinylated anti-human IgG capture molecule F(ab')<sub>2</sub><h-Fc $\gamma$ > BI (Dianova) at 0.1  $\mu\text{g}/\text{mL}$  for 1 h at room temperature or alternatively over night at 4°C and subsequently washed three times with 200  $\mu\text{L}/\text{well}$  PBS, 0.05% Tween (PBST, Sigma). 100  $\mu\text{L}/\text{well}$  of a dilution series in PBS (Sigma) of the respective antibody containing cell culture supernatants was added to the wells and incubated for 1-2 h on a microtiterplate shaker at room temperature. The wells were washed three times with 200  $\mu\text{L}/\text{well}$  PBST and bound antibody was detected with 100  $\mu\text{L}$  F(ab')<sub>2</sub><hF $\gamma$ >POD (Dianova) at 0.1  $\mu\text{g}/\text{mL}$  as detection antibody for 1-2 h on a microtiterplate shaker at room temperature. Unbound detection antibody was washed away three times with 200  $\mu\text{L}/\text{well}$  PBST and the bound detection antibody was detected by addition of 100  $\mu\text{L}$  ABTS/well. Determination of absorbance was performed on a Tecan Fluor Spectrometer at a measurement wavelength of 405 nm (reference wavelength 492 nm).

### Protein purification

Proteins were purified from filtered cell culture supernatants referring to standard protocols. In brief, antibodies were applied to a Protein A Sepharose column (GE healthcare) and washed with PBS. Elution of antibodies was achieved at pH 2.8 followed by immediate neutralization of the sample. Aggregated protein was separated from monomeric antibodies by size exclusion chromatography (Superdex 200, GE Healthcare) in PBS or in 20 mM Histidine, 150 mM NaCl pH 6.0. Monomeric antibody fractions were pooled, concentrated if required using e.g. a MILLIPORE Amicon Ultra (30 MWCO) centrifugal concentrator, frozen and stored at -20°C or -80°C. Part of the samples were provided for subsequent protein analytics and analytical characterization e.g. by SDS-PAGE, size exclusion chromatography or mass spectrometry.

### SDS-PAGE

The NuPAGE® Pre-Cast gel system (Invitrogen) was used according to the manufacturer's instruction. In particular, 10% or 4-12% NuPAGE® Novex® Bis-

TRIS Pre-Cast gels (pH 6.4) and a NuPAGE® MES (reduced gels, with NuPAGE® Antioxidant running buffer additive) or MOPS (non-reduced gels) running buffer was used.

#### Analytical size exclusion chromatography

5 Size exclusion chromatography for the determination of the aggregation and oligomeric state of antibodies was performed by HPLC chromatography. Briefly, Protein A purified antibodies were applied to a Tosoh TSKgel G3000SW column in 300 mM NaCl, 50 mM KH<sub>2</sub>PO<sub>4</sub>/K<sub>2</sub>HPO<sub>4</sub>, pH 7.5 on an Agilent HPLC 1100 system or to a Superdex 200 column (GE Healthcare) in 2 x PBS on a Dionex HPLC-System. The eluted protein was quantified by UV absorbance and  
10 integration of peak areas. BioRad Gel Filtration Standard 151–1901 served as a standard.

#### Mass spectrometry

The total deglycosylated mass of crossover antibodies was determined and  
15 confirmed via electrospray ionization mass spectrometry (ESI-MS). Briefly, 100 µg purified antibodies were deglycosylated with 50 mU N-Glycosidase F (PNGaseF, ProZyme) in 100 mM KH<sub>2</sub>PO<sub>4</sub>/K<sub>2</sub>HPO<sub>4</sub>, pH 7 at 37°C for 12–24 h at a protein concentration of up to 2 mg/ml and subsequently desalted via HPLC on a Sephadex G25 column (GE Healthcare). The mass of the respective heavy and light chains was  
20 determined by ESI-MS after deglycosylation and reduction. In brief, 50 µg antibody in 115 µl were incubated with 60 µl 1M TCEP and 50 µl 8 M Guanidinhydrochloride subsequently desalted. The total mass and the mass of the reduced heavy and light chains was determined via ESI-MS on a Q-Star Elite MS system equipped with a NanoMate source.

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#### Example 1

Production, expression, purification and characterization of bivalent, bispecific <IGF-1R-ANGPT2> antibody, wherein in the heavy chain of the <IGF-1R> antibody part, the heavy chain domain CH3 is replaced by a constant heavy chain domain CH1, and wherein in the heavy chain of the VL-VH/CL-CH1 exchange <ANGPT2> antibody, the heavy chain domain CH3 is replaced by a kappa  
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constant light chain domain Ck (abbreviated herein as <IGF-1R-ANGPT2> CH3-CH1/CH3-Ck exchange antibody).

Example 1A

5 Making of the expression plasmids for the modified Fc region with CH1-Ck for CH3-CH3 exchange

In order to show that the CH1-Ck for CH3-CH3 exchange can be applied for the generation of bispecific antibodies via induction of heterodimerization of the respective Fc regions an antibody construct according to Figure 5 was generated.  
10 For this sake plasmids for the co-expression of a wildtype <IGF-1R> antibody against IGF-1R and a VL-VH/CL-CH1 exchange <ANGPT2> antibody against Angiopoietin-2 were modified by exchange of the CH3 domain in the wildtype <IGF-1R> antibody with a CH1 domain and of the CH3 domain in the VL-VH/CL-CH1 exchange <ANGPT2> antibody with a CL (Ck) domain. The four  
15 corresponding plasmids were subsequently co-expressed and the generated antibody purified.

The sequence for the heavy variable domain including the respective leader sequence of the wildtype <IGF-1R> antibody heavy chain HC# with CH3-CH1 exchange was derived from a human <IGF-1R> antibody heavy chain (SEQ ID NO:  
20 1) described in WO 2005/005635, and the heavy and light chain constant domains were derived from a human antibody (C-kappa and IgG1). The sequence for the wildtype <IGF-1R> antibody light chain LC (SEQ ID NO: 2) is described in WO 2005/005635.

In order to induce heterodimerization with a different heavy chain containing a CL (Ck) domain the gene segments encoding the <IGF-1R> antibody leader sequence,  
25 heavy chain variable domain (VH), heavy chain constant domain 1 (CH1), hinge and constant domain CH2 (VH-CH1-Hinge-CH2) were joined and fused to the 5'-end of a heavy chain constant domain 1 (CH1) instead of the heavy chain constant domain 3 (CH3). Linker sequences were optimized and differ from the natural  
30 sequences. The DNA coding for the respective fusion protein resulting from the exchange of the CH3 domain by the CH1 domain (CH3-CH1 exchange) was generated by gene synthesis and is denoted <IGF-1R> HC# (SEQ ID NO: 3) in the following.

The sequences for the heavy and light chain variable domains of the Angiopoietin-2 <ANGPT2> VL-VH/CL-CH1 exchange antibody including the respective leader sequences described in this example were derived from a human wildtype <ANGPT2> antibody heavy chain (SEQ ID NO: 4) and a light chain (SEQ ID NO: 5) described in WO 2006/045049 and the heavy and light chain constant domains were derived from a human antibody (C-kappa and IgG1). In order to obtain the respective <ANGPT2> VL-VH/CL-CH1 exchange antibody the following constructs were generated:

The gene segments encoding the <ANGPT2> antibody leader sequence, light chain variable domain (VL) and the human kappa-light chain constant domain (CL) were joined and fused to the 5'-end of the Fc domains of the human  $\gamma$ 1-heavy chain constant domains (Hinge-CH2-CH3). The DNA coding for the respective fusion protein resulting from the exchange of VH and CH1 domains by VL and CL domains was generated by gene synthesis and is denoted VL-VH/CL-CH1 exchange <ANGPT2> HC\* (heavy chain\*) (SEQ ID NO: 6) in the following.

The gene segments for the <ANGPT2> antibody leader sequence, heavy chain variable domain (VH) and the human  $\gamma$ 1-heavy chain constant domains (CH1) were joined as independent chain. The DNA coding for the respective fusion protein resulting from the exchange of VL and CL domains by VH and CH1 domains was generated by gene synthesis and is denoted VL-VH/CL-CH1 exchange <ANGPT2> LC\* (light chain\*) (SEQ ID NO: 7) in the following.

In order to induce heterodimerization with a second heavy chain containing a CH1 domain the sequence for the modified VL-VH/CL-CH1 exchange <ANGPT2> antibody heavy chain\* HC\* (SEQ ID NO: 6) was modified by the exchange of the CH3 domain by a Ck domain (CH3-Ck exchange). For this purpose .the gene segments encoding the <ANGPT2> antibody leader sequence, light chain variable domain (VL), light chain constant domain 1 (CL), hinge and constant domain CH2 (VL-CL-Hinge-CH2) from SEQ ID NO: 6 were joined and fused to the 5'-end of a kappa light chain constant domain (Ck) instead of the heavy chain constant domain 3 (CH3). Linker sequences were optimized and differ from the natural sequences. Two sequences were evaluated either ending without a C-terminal cysteine (SEQ ID NO: 8) or ending with a C-terminal cysteine (SEQ ID NO: 9). The DNA coding for the respective fusion protein resulting from the exchange of the CH3 domain by the kappa CL domain (CH3-Ck exchange ) was generated by gene

synthesis and was denoted <ANGPT2> HC## (SEQ IDs NO: 8 and NO:9) in the following.

Figure 6 and Figure 7 show a schematic view of the protein sequence of the modified <IGF-1R> heavy chain HC# and the modified VL-VH/CL-CH1 exchange <ANGPT2> antibody heavy chain HC## with or without C-terminal Cysteine responsible for the heterodimerization of the respective bispecific antibodies. Figure 8 shows an overview of the applied 4 vectors to generate bispecific antibodies (4-vector system).

### Example 1B

10 **Transient expression and purification of the bispecific <IGF-1R-ANGPT2> CH3-CH1/CH3-Ck exchange antibody with modified Fc region**

In the following, the four plasmids coding for the modified <IGF-1R> heavy chain HC# (pUC-HC#-IGF-1R) (SEQ ID NO: 3) and for the modified VL-VH/CL-CH1 exchange <ANGPT2> antibody heavy chain HC## (pUC-HC##-ANGPT2) (either SEQ ID NO: 8 without Cysteine residue or SEQ ID NO: 9 with Cysteine residue) were transiently co-expressed at equimolar ratios together with the respective light chain vectors for the <IGF-1R> wildtype light chain LC (pUC-LC-IGF-1R) (SEQ ID NO: 2) and the modified VL-VH/CL-CH1 exchange <ANGPT2> antibody light chain LC\* (pUC-LC\*-ANGPT2) (SEQ ID: 7), respectively as described above (Figure 8). Bispecific antibodies were subsequently purified via Protein A followed by size exclusion chromatography as described above. Figure 9 shows the SDS-PAGE of the purified protein from the two expressions either with the plasmid coding for the modified VL-VH/CL-CH1 exchange <ANGPT2> antibody heavy chain HC## either without or with the C-terminal Cysteine. The SDS-PAGE indicated that in the purified antibodies indeed 4 different protein chains from the desired functional bispecific <IGF-1R-ANGPT2> CH3-CH1/CH3-Ck exchange antibody were present in similar ratios.

### Example 1E

30 **Detection of functional bispecific <IGF-1R-ANGPT2> CH3-CH1/CH3-Ck exchange antibodies with modified Fc region with CH3-CH1/CH3-Ck exchange in a cellular FACS bridging assay on I24 IGF-1R expressing cells**

In order to confirm the presence of functional bispecific <IGF-1R-ANGPT2> CH3-CH1/CH3-Ck exchange antibodies with modified Fc region with CH1-Ck for CH3-



CH3 exchange a cellular FACS IGF-1R-ANGPT2 bridging assay on I24 cells (NIH3T3 cells expressing recombinant human IGF-1R, Roche) is performed. The assay principle is depicted in Figure 10. A bispecific <IGF-1R-ANGPT2> that is present in the purified antibody mix, respectively; is capable of binding to IGF-1R in I24 cells and to ANGPT2 simultaneously; and thus will bridge its two target antigens with the two opposed Fab regions.

5 Briefly,  $5 \times 10^5$  I24 cells per FACS tube are incubated with total purified antibody mix and incubated on ice for 1 h. The respective purified antibody is applied to the I24 cells. Unbound antibody is washed away with 4 ml ice cold PBS (Gibco) + 2% FCS (Gibco), cells are centrifuged (5 min at 400 g) and bound bispecific antibody is detected with 50  $\mu$ l 2  $\mu$ g/mL human Angiopoietin-2 (R&D Systems) for 1 h on ice. Subsequently, unbound Angiopoietin-2 is washed away once or twice with 4 ml ice cold PBS (Gibco) + 2% FCS (Gibco), cells are centrifuged (5 min at 400 g) and bound Angiopoietin-2 is detected with 50  $\mu$ l 5  $\mu$ g/mL <Ang-2>mIgG1-Biotin antibody (BAM0981, R&D Systems) for 45 min on ice; alternatively, cells are incubated with 50  $\mu$ l 5  $\mu$ g/mL mIgG1-Biotin-Isotype control (R&D Systems). Unbound detection antibody is washed away with 4 ml ice cold PBS (Gibco) + 2% FCS (Gibco), cells are centrifuged (5 min at 400 g) and bound detection antibody is detected with 50  $\mu$ l 1:400 Streptavidin-PE conjugate (Invitrogen/Zymed) for 45 min on ice protected from light. Unbound Streptavidin-PE conjugate is washed away with 4 ml ice cold PBS + 2% FCS. Subsequently, cells are centrifuged (5 min 400 g), resuspended in 300-500  $\mu$ L PBS and bound Streptavidin-PE conjugate is quantified on a FACSCalibur or FACS Canto (BD (FL2 channel, 10.000 cells per acquisition). During the experiment the respective isotype controls are included to exclude any unspecific binding events. In addition, purified monospecific, bivalent IgG1 antibodies <IGF-1R> and <ANGPT2> are included as controls.

## Patent Claims

1. A bivalent, bispecific antibody, comprising:
  - a) the light chain and heavy chain of an antibody specifically binding to a first antigen,  
5 wherein the heavy chain domain CH3 is replaced by a constant heavy chain domain CH1;
  - b) the light chain and heavy chain of an antibody specifically binding to a second antigen,  
10 wherein the constant heavy chain domain CH3 is replaced by a constant light chain domain CL.
2. The antibody according to claim 1, characterized in that  
15 the light chain and heavy chain of either said first antibody specifically binding to a first antigen or said second antibody specifically binding the second antigen is altered  
by the replacement of the variable domains VL and VH by each other,  
and/or  
by the replacement of the variable domains CL and CH1 by each other.
- 20 3. A method for the preparation of an a bivalent, bispecific antibody according to claim 1 comprising the steps of
  - a) transforming a host cell with
    - vectors comprising nucleic acid molecules encoding the light chain  
25 and heavy chain of an antibody specifically binding to a first antigen,  
wherein the heavy chain domain CH3 is replaced by a constant heavy chain domain CH1; and
    - vectors comprising nucleic acid molecules encoding the light chain  
30 and heavy chain of an antibody specifically binding to a second antigen,  
wherein the constant heavy chain domain CH3 is replaced by a constant light chain domain CL ;

b) culturing the host cell under conditions that allow synthesis of said antibody molecule; and

c) recovering said antibody molecule from said culture.

4. A host cell comprising:

5 - vectors comprising nucleic acid molecules encoding the light chain and heavy chain of an antibody specifically binding to a first antigen, wherein the heavy chain domain CH3 is replaced by a constant heavy chain domain CH1; and

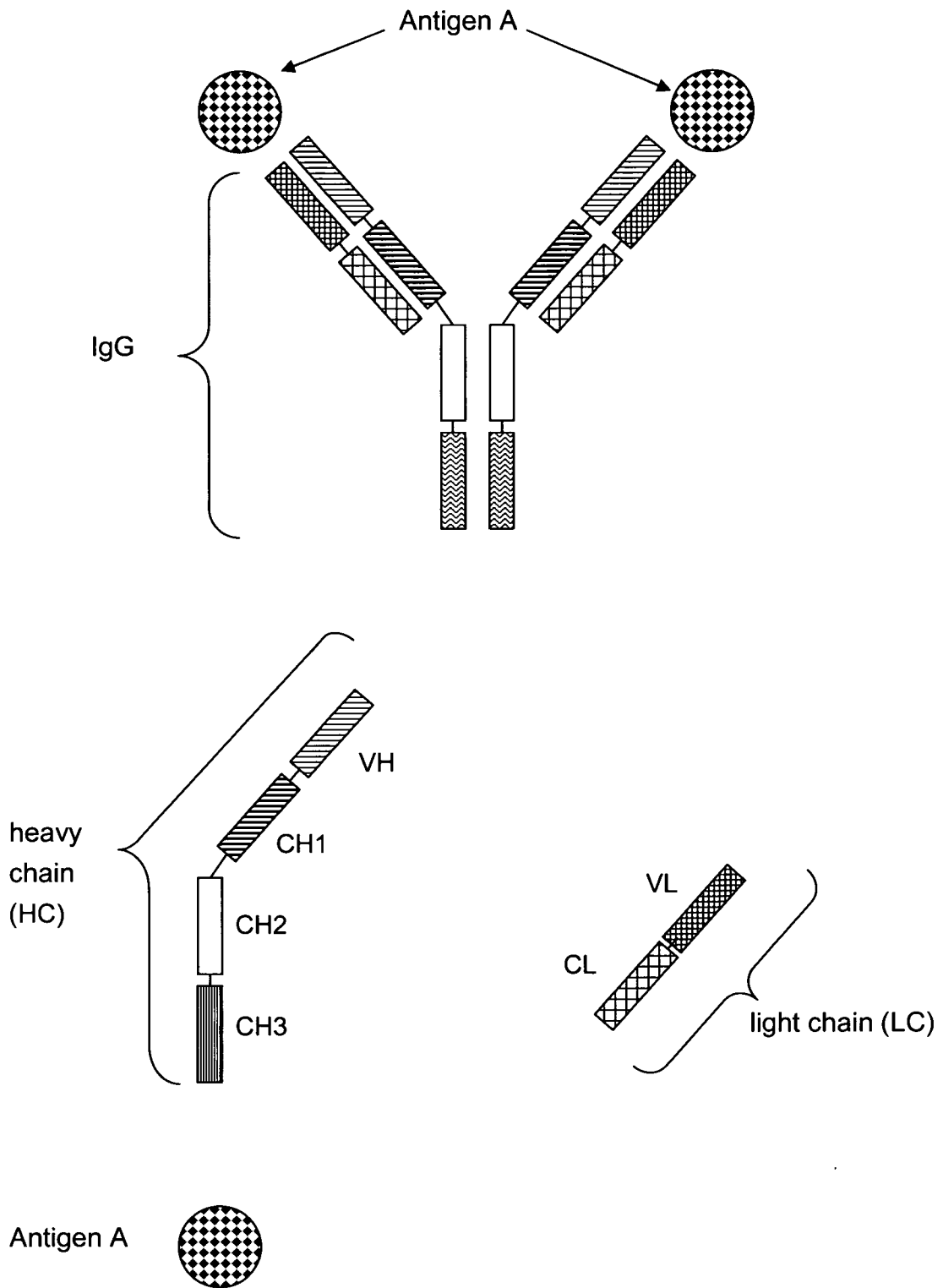
10 - vectors comprising nucleic acid molecules encoding the light chain and heavy chain of an antibody specifically binding to a second antigen, wherein the constant heavy chain domain CH3 is replaced by a constant light chain domain CL.

15 5. A composition, preferably a pharmaceutical or a diagnostic composition of the bivalent, bispecific antibody according to claims 1 to 2

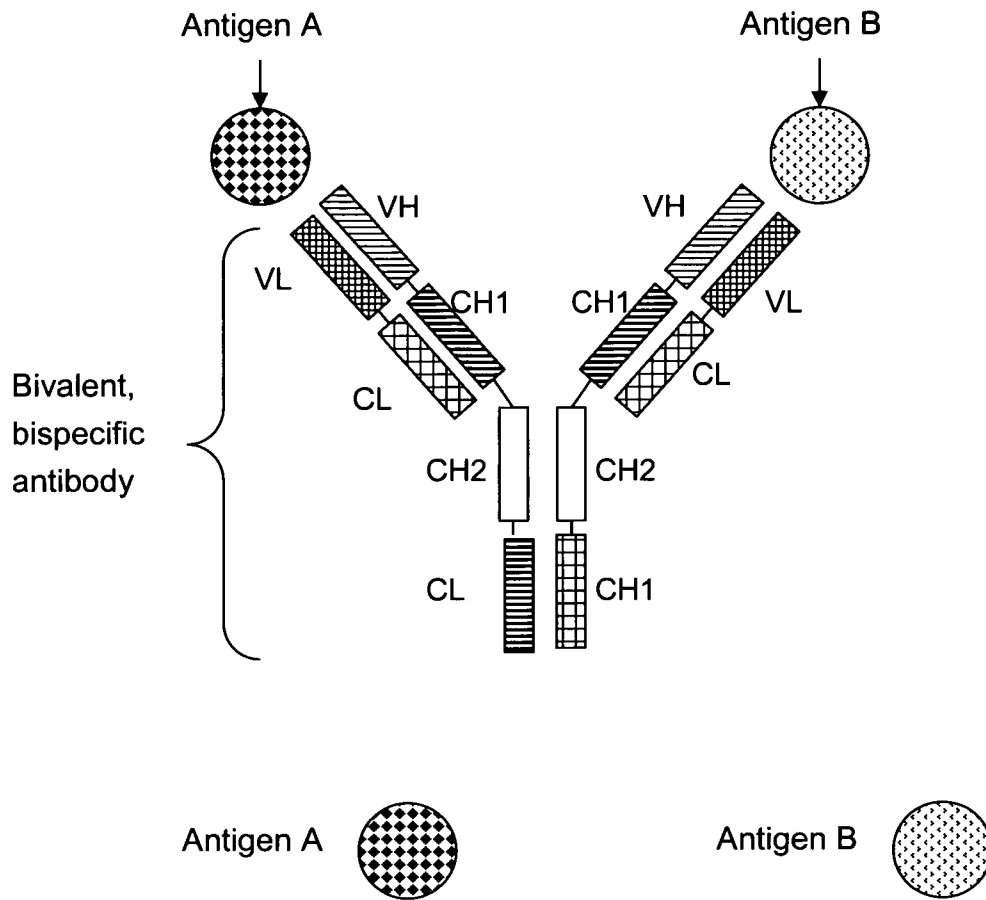
6. A pharmaceutical composition comprising a bivalent, bispecific antibody according to claims 1 to 2 and at least one pharmaceutically acceptable excipient.

20 7. A method for the treatment of a patient in need of therapy, characterized by administering to the patient a therapeutically effective amount of a bivalent, bispecific antibody according to claims 1 to 2.

Fig. 1



**Fig. 2**



**Fig. 3**

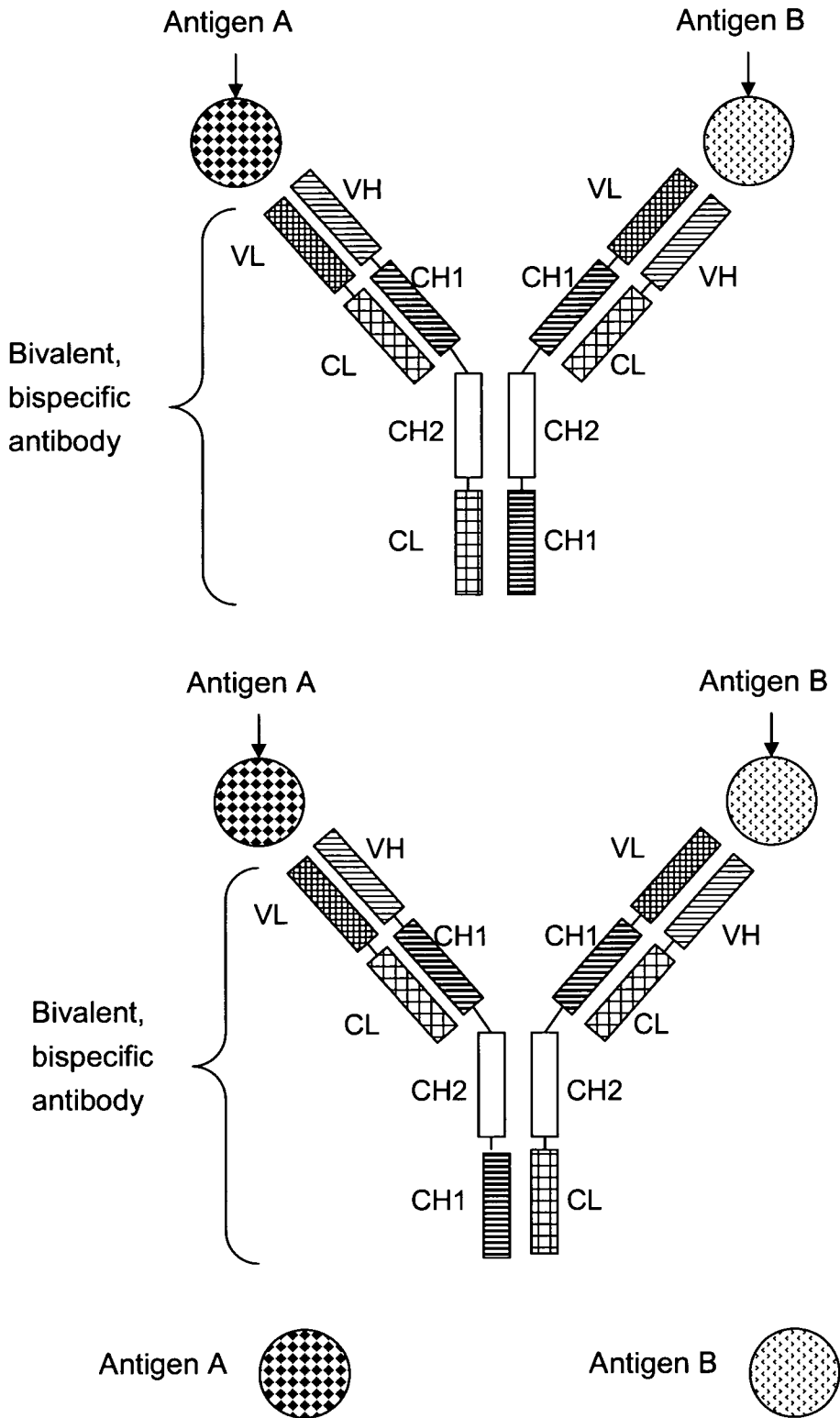


Fig. 4

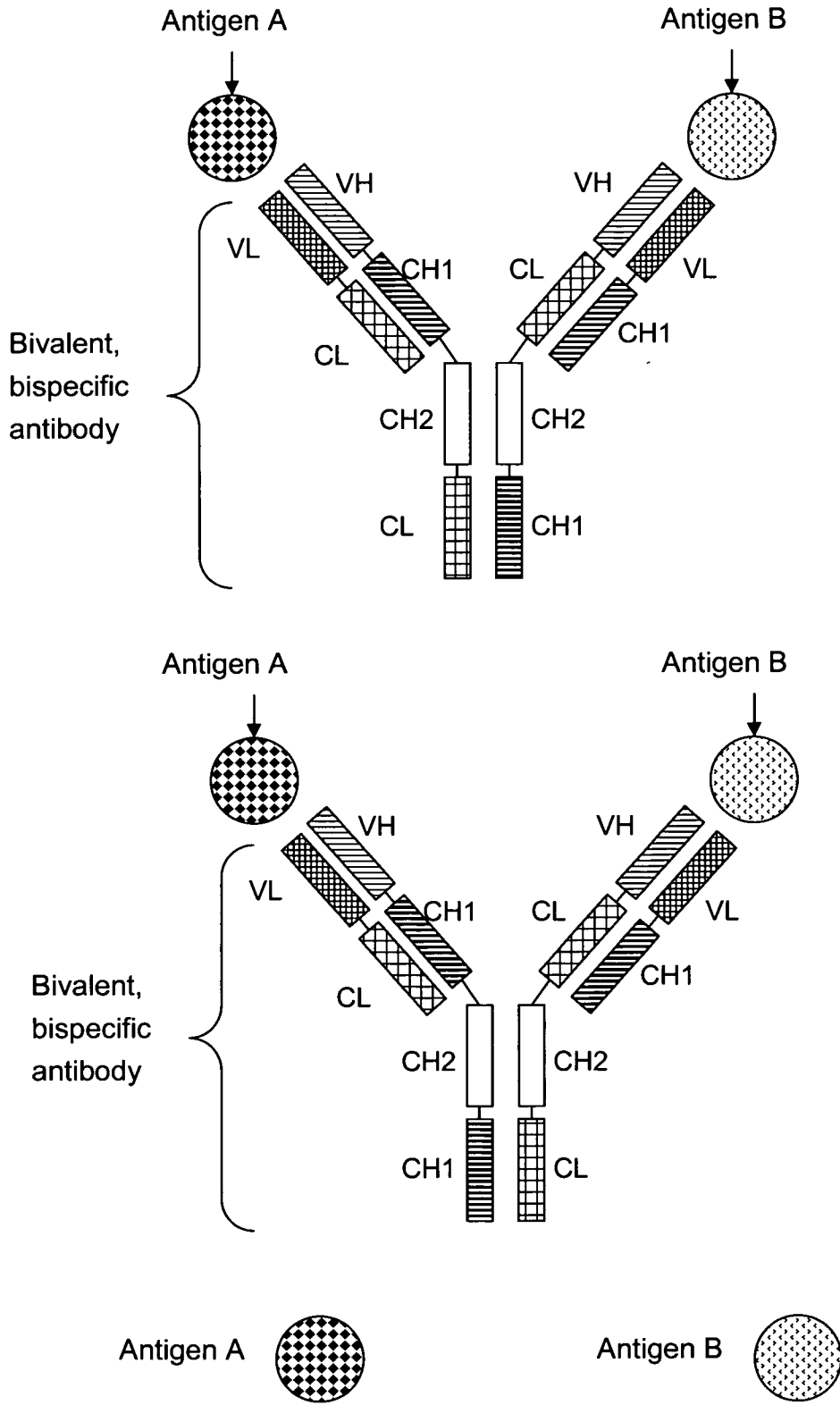
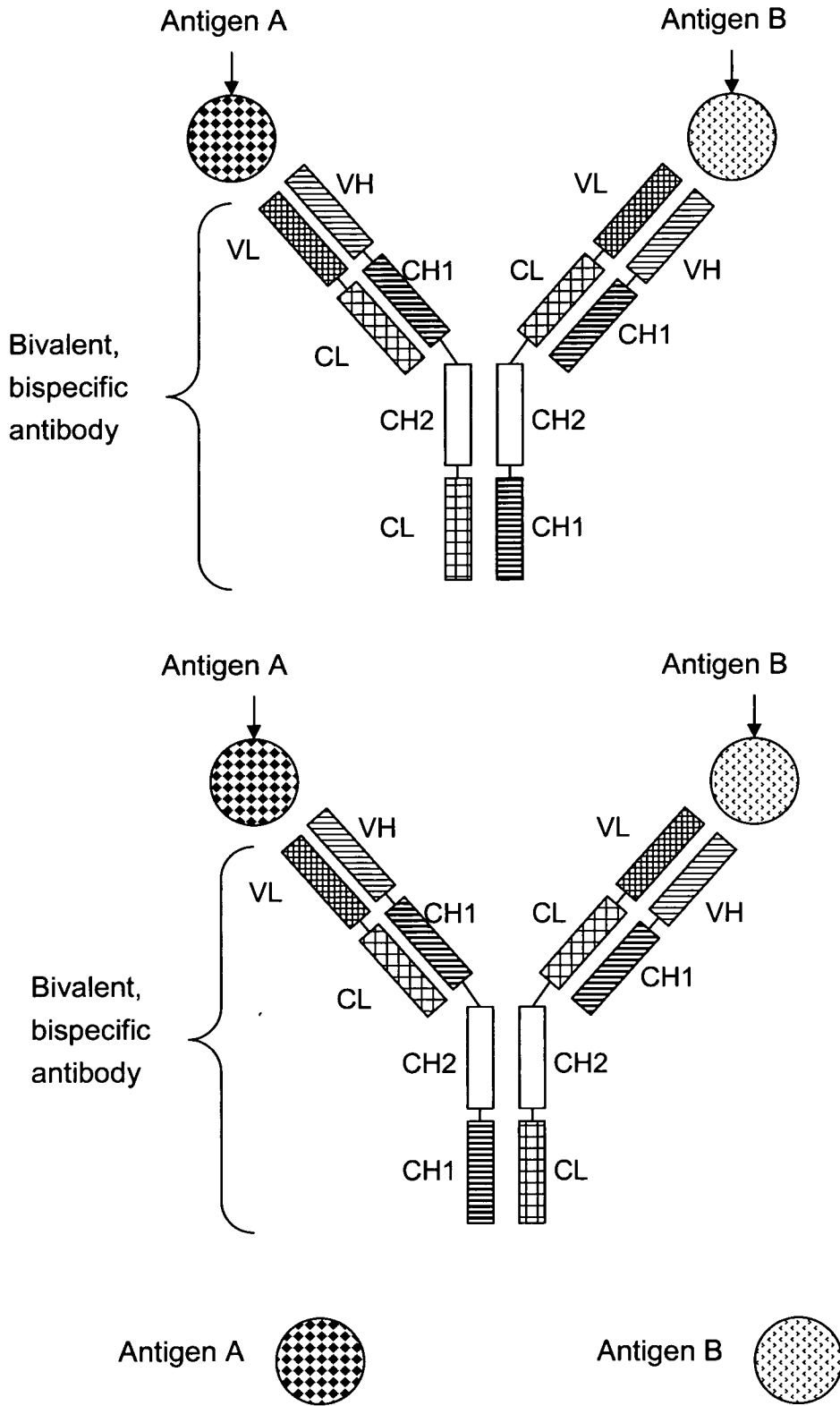
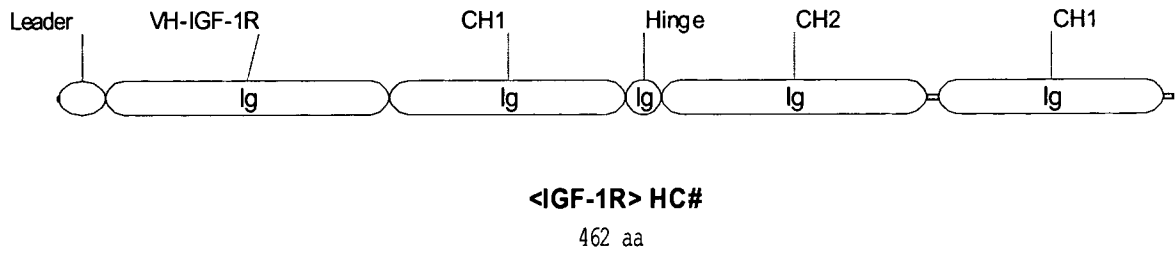


Fig. 5

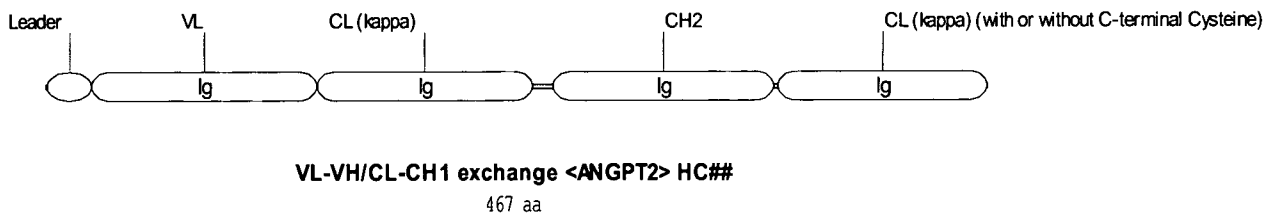




**Fig. 6**



**Fig. 7**



**Fig. 8a**

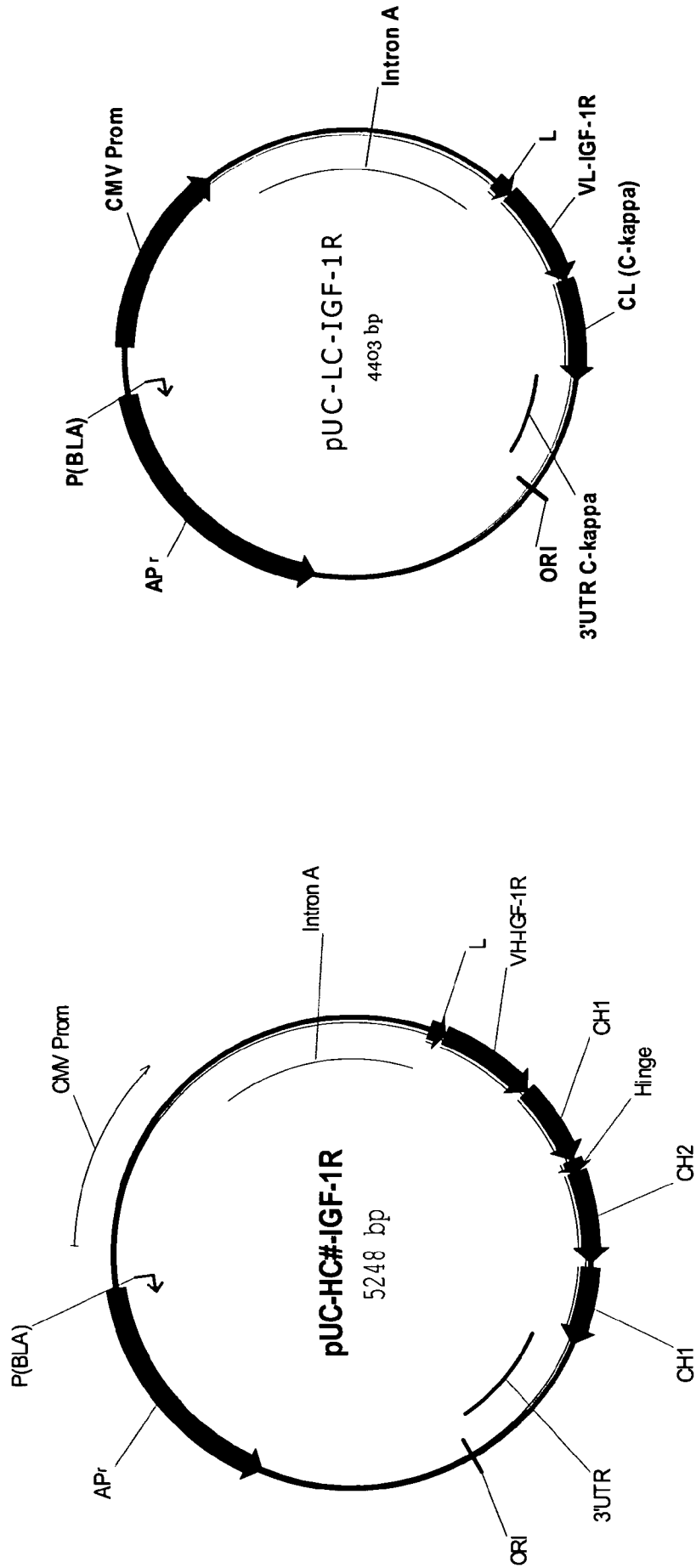
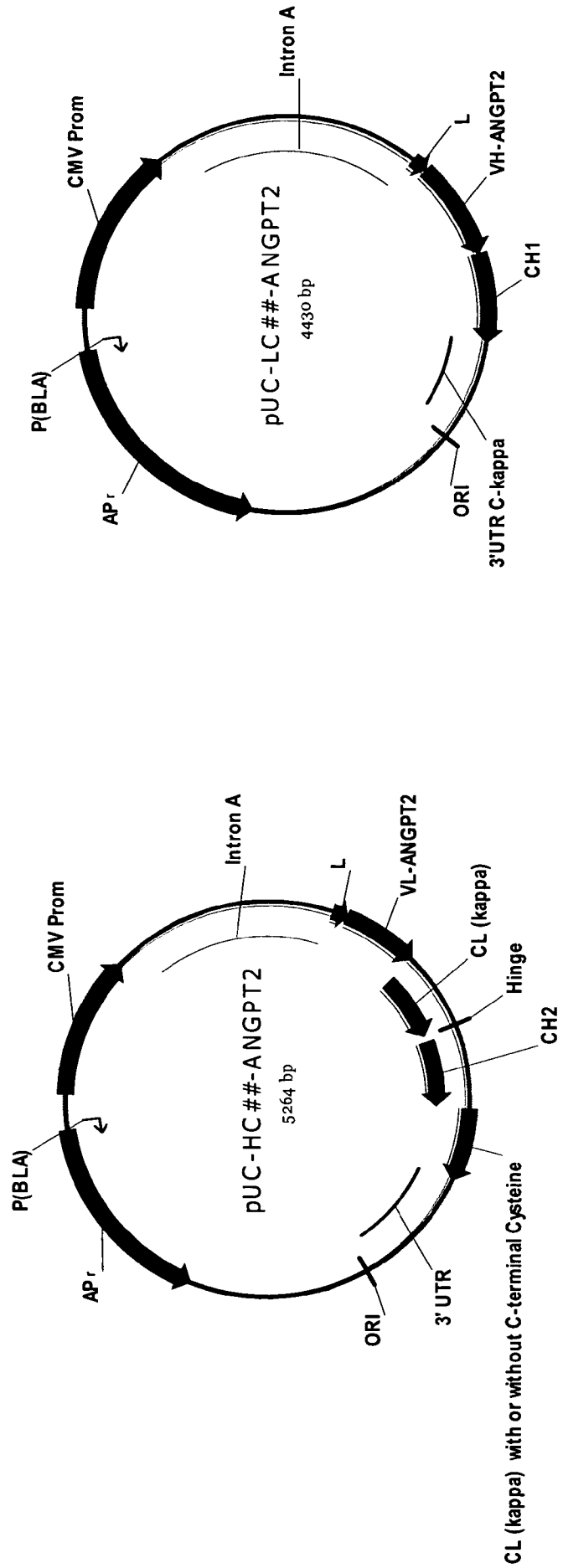
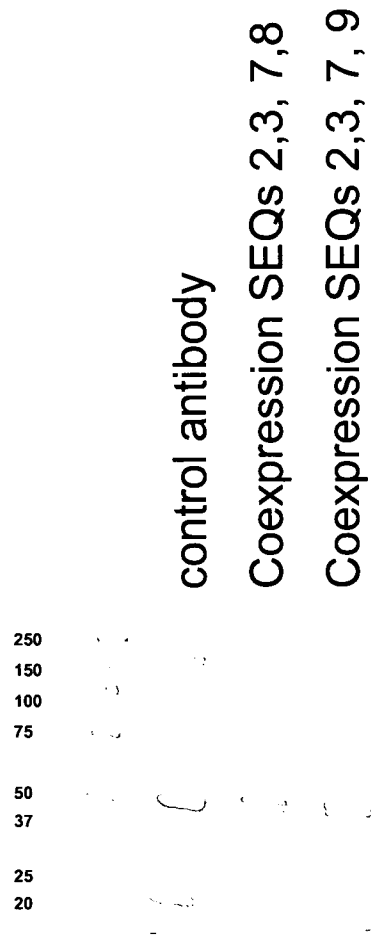


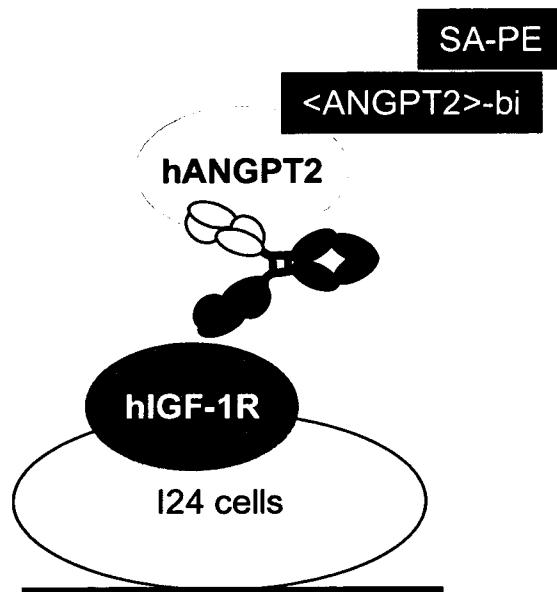
Fig. 8b



**Fig. 9**



**Fig. 10**



## INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2008/010705

<b>A. CLASSIFICATION OF SUBJECT MATTER</b>		
INV. C07K16/46		
ADD. C07K16/22      C07K16/28      C07K19/00      A61K39/395		
According to International Patent Classification (IPC) or to both national classification and IPC		
<b>B. FIELDS SEARCHED</b>		
Minimum documentation searched (classification system followed by classification symbols)		
C07K   A61K		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practical, search terms used)		
EPO-Internal, BIOSIS, EMBASE, Sequence Search, WPI Data		
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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<input checked="" type="checkbox"/>	Further documents are listed in the continuation of Box C.	<input checked="" type="checkbox"/>
		See patent family annex.
* Special categories of cited documents :		
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International application No

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
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Information on patent family members

International application No

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