Bivalent, bispecific antibodies

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

Background of the Invention

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.

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 2001077342; and Morrison, S., L., Nature Biotech. 25 (2007) 1233-1234.

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; Fischer, N., and Léger, O., Pathobiology 74 (2007) 3-14; Shen, J., et. al., J. Immunol. Methods 318 (2007) 65-74; Wu, C., et al., Nature Biotech 25 (2007) 1290-1297).

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., and 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 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 antibody dependent cellular cytotoxicity (ADCC), which are mediated through the Fcpart by maintaining a high degree of similarity to naturally occurring antibodies.

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 A.C. Cuello, 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., Protein Eng. 9 (1996) 617-621; 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., et al., 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 2006/093794 relates to heterodimeric protein binding compositions. WO 99/37791 describes multipurpose antibody derivatives. Morrison et al the J. Immunolog, 160(1998) 2802-2808 refers to the influence of variable region domain exchange on the functional properties of IgG.

Summary of the Invention

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

a) the light chain and heavy chain of an antibody specifically binding to a first antigen; and

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

wherein the variable domains VL and VH are replaced by each other,

and

wherein the constant domains CL and CH1 are replaced by each other.

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

-vectors comprising nucleic acid molecules encoding the light chain and heavy chain of an antibody specifically binding to a first antigen, and

-vectors comprising nucleic acid molecules encoding the light chain and heavy chain of an antibody specifically binding to a second antigen,

wherein the variable domains VL and VH are replaced by each other,

and

wherein the constant domains CL and CH1 are replaced by each other;

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

- vectors comprising nucleic acid molecules encoding the light chain and heavy chain of an antibody specifically binding to a first antigen, and

- vectors comprising nucleic acid molecules encoding the light chain and heavy chain of an antibody specifically binding to a second antigen,
wherein the variable domains VL and VH are replaced by each other,
and
wherein the constant domains CL and CH1 are replaced by each other.

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.

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:

a) the light chain and heavy chain of an antibody specifically binding to a first antigen; and

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

wherein the variable domains VL and VH are replaced by each other,

and

wherein the constant domains CL and CH1 are replaced by each other.

Therefore said bivalent, bispecific antibody, comprises:

a) a first light chain and a first heavy chain of an antibody specifically binding to a first antigen; and

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

wherein the variable domains VL and VH of the second light chain and the second heavy chain are replaced by each other,

and

wherein the constant domains CL and CH1 of the second light chain and the second heavy chain are replaced by each other.

Thus for said antibody specifically binding to a second antigen the following applies:

within the light chain

the variable light chain domain VL is replaced by the variable heavy chain domain VH of said antibody, and the constant light chain domain CL is replaced by the constant heavy chain domain CH1of said antibody;

and within the heavy chain

the variable heavy chain domain VH is replaced by the variable light chain domain VL of said antibody, and the constant heavy chain domain CH1 is replaced by the constant light chain domain CL of said antibody.

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). 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 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 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., Immunobiology, 5th ed., Garland Publishing (2001); and Woof J, Burton D Nat Rev 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 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: α, δ, ϵ, γ, and μ (Janeway, C.A., Jr., et al., Immunobiology, 5th ed., Garland Publishing (2001)). The type of heavy chain present defines the class of antibody; these chains are found in IgA, IgD, IgE, IgG, and IgM antibodies, respectively (Rhoades RA, Pflanzer RG (2002). Human Physiology, 4th ed., Thomson Learning). Distinct heavy chains differ in size and composition; α and γ contain approximately 450 amino acids, while μ and ϵ 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 antibodies of different isotype. Heavy chains γ, α and δ 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 μ and ϵ have a constant region composed of four constant domains CH1, CH2, CH3, and CH4 (Janeway, C.A., Jr., et al., Immunobiology, 5th ed., Garland Publishing (2001)). 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.

In mammals there are only two types of light chain, which are called lambda (λ) and kappa (κ). 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. Preferably the light chain is a kappa (κ) light chain, and the constant domain CL is preferably C kappa (κ).

The terms "monoclonal antibody" or "monoclonal antibody composition" as used 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 bispecific antibody according to the invention is derived, have an Fc part 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 0 307 434. 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; Brüggemann, 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, S.P.C., et al. and Boerner et al. are also available for the preparation of human monoclonal antibodies (Cole, S.P.C., et al., Monoclonal Antibodies and Cancer Therapy, Alan R. Liss, Inc., New York (1986), pp. 77-96; 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 β-sheet conformation and the CDRs may form loops connecting the β-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).

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:

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.

According to the invention, the ratio of a desired bivalent, bispecific antibody compared to undesired side products can be improved by the replacement of certain domains in only one pair of heavy chain and light chain (HC/LC). While the first of the two HC/LC pairs originates from an antibody specifically binding to a first antigen and is left essentially unchanged, the second of the two HC/LC pairs originates from an antibody specifically binding to a second antigen , and is altered by the following replacement:

- light chain: replacement of the variable light chain domain VL by the variable heavy chain domain VH of said antibody specifically binding to a second antigen , and the constant light chain domain CL by the constant heavy chain domain CH1 of said antibody specifically binding to a second antigen , and
- heavy chain: replacement of the variable heavy chain domain VH by the variable light chain domain VL of said antibody specifically binding to a second antigen, and the constant heavy chain domain CH1 by the constant light chain domain CL of said antibody specifically binding to a second antigen.

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; and

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

wherein said light chain (of an antibody specifically binding to a second antigen) contains a variable domain VH instead of VL

and a constant domain CH1 instead of CL

wherein said heavy chain(of an antibody specifically binding to a second antigen) contains a variable domain VL instead of VH

and a constant domain CL instead of CH1.

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 one of the following two alternatives:

A) First alternative (see Fig. 3):

The CH3 domains of said bivalent, bispecific antibody according to the invention can be altered by the "knob-into-holes" technology which is described in detail with several examples in e.g. WO 96/027011, Ridgway J.B., et al., Protein Eng 9 (1996) 617–621; and Merchant, A.M., et al., Nat Biotechnol 16 (1998) 677–681. In this method the interaction surfaces of the two CH3 domains are altered to increase the heterodimerisation of both heavy chains containing these two CH3 domains. Each of the two CH3 domains (of the two heavy chains) can be the "knob", while the other is the "hole". The introduction of a disulfide bridge stabilizes the heterodimers (Merchant, A.M, et al., Nature Biotech 16 (1998) 677-681; Atwell, S., et al. J. Mol. Biol. 270 (1997) 26–35) and increases the yield.

Therefore in preferred embodiment the CH3 domains of a bivalent, bispecific antibody wherein the first CH3 domain and second CH3 domain each meet at an interface which comprises an original interface between the antibody CH3 domains are altered by the "knob-into-holes" technology including further stabilization by introduction of a disulfide bridge in the CH3 domains (described in WO 96/027011, Ridgway, J.B., et al., Protein Eng 9 (1996) 617-621; Merchant, A.M., et al, Nature Biotech 16 (1998) 677-681; and Atwell, S., et al., J. Mol. Biol. 270 (1997) 26–35) to promote the formation of the bivalent, bispecific antibody.

Thus in one aspect of the invention said bivalent, bispecific antibody is characterized in that

the CH3 domain of one heavy chain and the CH3 domain of the other heavy chain each meet at an interface which comprises an original interface between the antibody CH3 domains;

wherein said interface is altered to promote the formation of the bivalent, bispecific antibody, wherein the alteration is characterized in that:

a) the CH3 domain of one heavy chain is altered,

so that within the original interface the CH3 domain of one heavy chain that meets the original interface of the CH3 domain of the other heavy chain within the bivalent, bispecific antibody,
an amino acid residue is replaced with an amino acid residue having a larger side chain volume, thereby generating a protuberance within the interface of the CH3 domain of one heavy chain which is positionable in a cavity within the interface of the CH3 domain of the other heavy chain

and

b) the CH3 domain of the other heavy chain is altered,

so that within the original interface of the second CH3 domain that meets the original interface of the first CH3 domain within the bivalent, bispecific antibody an amino acid residue is replaced with an amino acid residue having a smaller side chain volume, thereby generating a cavity within the interface of the second CH3 domain within which a protuberance within the interface of the first CH3 domain is positionable.

Preferably said amino acid residue having a larger side chain volume is selected from the group consisting of arginine (R), phenylalanine (F), tyrosine (Y), tryptophan (W).

Preferably said amino acid residue having a smaller side chain volume is selected from the group consisting of alanine (A), serine (S), threonine (T), valine (V).

In one aspect of the invention both CH3 domains are further altered the introduction of cysteine (C) as amino acid in the corresponding positions of each CH3 domain such that a disulfide bridge between both CH3 domains can be formed.

In another preferred embodiment of the invention both CH3 domains are altered by the use of residues R409D; K370E (K409D) for knobs residues and D399K; E357K for hole residues described eg. in EP 1870459A1.

or

<u>B) Second alternative (see Figure 4):</u>

by the replacement of one constant heavy chain domain CH3 by a constant heavy chain domain CH1; and the other constant heavy chain domain CH3is replaced by a constant light chain domain CL.

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 (λ) or kappa (κ) type, preferably the kappa (κ) type.

Thus one preferred embodiment of the invention is a bivalent, bispecific antibody, comprising:
a) the light chain and heavy chain of an antibody specifically binding to a first antigen; and
b) the light chain and heavy chain of an antibody specifically binding to a second antigen,
wherein the variable domains VL and VH are replaced by each other, and
wherein the constant domains CL and CH1 are replaced by each other,

and wherein optionally

c) the CH3 domain of one heavy chain and the CH3 domain of the other heavy chain each meet at an interface which comprises an original interface between the antibody CH3 domains;

wherein said interface is altered to promote the formation of the bivalent, bispecific antibody, wherein the alteration is characterized in that:

ca) the CH3 domain of one heavy chain is altered,

so that within the original interface the CH3 domain of one heavy chain that meets the original interface of the CH3 domain of the other heavy chain within the bivalent, bispecific

antibody,
an amino acid residue is replaced with an amino acid residue having a larger side chain volume, thereby generating a protuberance within the interface of the CH3 domain of one heavy chain which is positionable in a cavity within the interface of the CH3 domain of the other heavy chain

and

cb) the CH3 domain of the other heavy chain is altered,

so that within the original interface of the second CH3 domain that meets the original interface of the first CH3 domain within the bivalent, bispecific antibody
an amino acid residue is replaced with an amino acid residue having a smaller side chain volume, thereby generating a cavity within the interface of the second CH3 domain within which a protuberance within the interface of the first CH3 domain is positionable;

or d)

one constant heavy chain domain CH3 is replaced by a constant heavy chain domain CH1; and the other constant heavy chain domain CH3 is replaced by a constant light chain domain CL

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 epitopes on proteins (as different antigens within the meaning of the invention), and polysaccharides. This mainly includes parts (coats, capsules, cell walls, flagella, fimbrae, 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 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.

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 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.

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.

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.

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.

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.

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

-vectors comprising nucleic acid molecules encoding the light chain and heavy chain of an antibody specifically binding to a first antigen, and

-vectors comprising nucleic acid molecules encoding the light chain and heavy chain of an antibody specifically binding to a second antigen,
wherein the variable domains VL and VH are replaced by each other,
and,
wherein the constant domains CL and CH1 are replaced by each other;

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

c) recovering said antibody molecule from said culture.

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 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 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;

-a second nucleic acid sequence encoding the heavy chain of said antibody specifically binding to a first antigen;

-a third nucleic acid sequence encoding the light chain of an antibody specifically binding to a second antigen, wherein the variable light chain domain VL is replaced by the variable heavy chain domain VH, and wherein the constant light chain domain CL is replaced by the constant heavy chain domain CH1; and

-a fourth nucleic acid sequence encoding the heavy chain of said antibody specifically binding to a second antigen, wherein the variable heavy chain domain VH is replaced by the variable light chain domain VL, and wherein the constant heavy chain domain CH1 is replaced by the constant light chain domain CL.

A further embodiment of the invention is a host cell comprising

- vectors comprising nucleic acid molecules encoding the light chain and heavy chain of an antibody specifically binding to a first antigen, and

- vectors comprising nucleic acid molecules encoding the light chain and heavy chain of an antibody specifically binding to a second antigen,
wherein the variable domains VL and VH are replaced by each other,
and
wherein the constant domains CL and CH1 are replaced by each other.

A further embodiment of the invention is a host cell comprising

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, 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 variable domains VL and VH are replaced by each other,

and

wherein the constant domains CL and CH1 are replaced by each other.

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 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.

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 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.

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 (1973) 456-467. However, other methods for introducing DNA into cells such as by electroporation, nucleofection, 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) 151-160; 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, PER.C6 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 are 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 the heavy chain* (HC*) of <IGF-1R> 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.
SEQ ID NO: 4	amino acid sequence of the light chain* (LC*) of <IGF-1R> 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.
SEQ ID NO: 5	amino acid sequence of IGF-1R ectodomain His-Streptavidin binding peptide-tag (IGF-1R-His-SBP ECD)
SEQ ID NO: 6	amino acid sequence of wild type Angiopoietin-2 <ANGPT2> antibody heavy chain
SEQ ID NO: 7	amino acid sequence of wild type Angiopoietin-2 <ANGPT2> antibody light chain
SEQ ID NO: 8	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.
SEQ ID NO: 9	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.
SEQ ID NO: 10	amino acid sequence of CH3 domain (Knobs) with a T366W exchange for use in the knobs-into-holes technology
SEQ ID NO: 11	amino acid sequence CH3 domain (Hole) with a T366S, L368A, Y407V exchange for use in the knobs-into-holes technology
SEQ ID NO: 12	amino acid sequence of wild type <VEGF> antibody heavy chain
SEQ ID NO: 13 and 14	amino acid sequence of wild type <VEGF> antibody light chain with and without leader

SEQ ID NO: 15 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 and the CH3 domain carries an amino acid sequence with a T366S, L368A, Y407V exchange (Hole) for use in the knobs-into-holes technology

SEQ ID NO: 16 amino acid sequence of wild type <VEGF> antibody heavy chain, wherein the CH3 domain carries an amino acid sequence with a T366W (Knobs) exchange for use in the knobs-into-holes technology

SEQ ID NO: 17 amino acid sequence of the heavy chain(G)* (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 with an additional Glycin insertion.

SEQ ID NO: 18 amino acid sequence of the light chain(G)* (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 with an additional Glycin insertion.

Description of the Figures

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.

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; and b) the light chain and heavy chain of an antibody specifically binding to a second antigen, wherein the variable domains VL and VH are replaced by each other, and

wherein the constant domains CL and CH1 are replaced by each other.

Figure 3 Schematic figure of a bivalent, bispecific antibody, comprising: a) the light chain and heavy chain of an antibody specifically binding to a first antigen; and b) the light chain and heavy chain of an antibody specifically binding to a second antigen, wherein the variable domains VL and VH are replaced by each other, and wherein the constant domains CL and CH1 are replaced by each other, and wherein the CH3 domains of both heavy chains are altered by the knobs-into-holes technology .

Figure 4 Schematic figure of a bivalent, bispecific antibody, comprising: a) the light chain and heavy chain of an antibody specifically binding to a first antigen; and b) the light chain and heavy chain of an antibody specifically binding to a second antigen, wherein the variable domains VL and VH are replaced by each other, and wherein the constant domains CL and CH1 are replaced by each other, and wherein one of the constant heavy chain domains CH3 of both heavy chains is replaced by a constant heavy chain domain CH1, and the other constant heavy chain domain CH3 is replaced by a constant light chain domain CL.

Figure 5 Protein sequence scheme of the heavy chain* <IGF-1R> HC* of the <IGF-1R> VL-VH/CL-CH1 exchange antibody

Figure 6 Protein sequence scheme of the light chain* <IGF-1R> LC* of the <IGF-1R> VL-VH/CL-CH1 exchange antibody

Figure 7 Plasmid map of heavy chain* <IGF-1R> HC* expression vector pUC-HC*-IGF-1R

Figure 8 Plasmid map of light chain* <IGF-1R> LC* expression vector pUC-LC*-IGF-1R

Figure 9 Plasmid map of the 4700-Hyg-OriP expression vector

Figure 10 SDS-PAGE of monospecific, bivalent <IGF-1R> VL-VH/CL-CH1 exchange antibody (IgG1*) with HC* and LC* isolated by

immunoprecipitation with Protein A Agarose from cell culture supernatants after transient transfection of HEK293E cells.

Figure 11 Binding of monospecific <IGF-1R> VL-VH/CL-CH1 exchange antibody and wildtype <IGF-1R> antibody to the IGF-1R ECD in an ELISA-based binding assay.

Figure 12 Plasmid map of heavy chain* <ANGPT2> HC* expression vector pUC-HC*-ANGPT2>

Figure 13 Plasmid map of light chain* <ANGPT2> LC* expression vector pUC-LC*-ANGPT2>

Figure 14 Reduced and non-reduced SDS-PAGE from purification of mix of A) monospecific <IGF-1R> VL-VH/CL-CH1 exchange antibody, B) bispecific <ANGPT2-IGF-1R> VL-VH/CL-CH1 exchange antibody and C)<ANGPT2> wildtype antibodies ("Bispecific VL-VH/CL-CH1 exchange mix") from cell culture supernatants by Protein A affinity chromatography followed by size exclusion chromatography and concentration

Figure 15 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/CL-CH1 exchange antibody

Figure 16 Results for Samples A to G 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/CL-CH1 exchange antibody in cell culture supernatants.

Sample	Cell IGF-1R	Antibody	hANGPT2	Detection antibody	Detection
A	I24	untreated	-	<Ang-2>mIgG1-Biotin	SA-PE
B	I24	untreated	2 µg/mL hANGPT2	<Ang-2>mIgG1-Biotin	SA-PE
C	I24	bispecific <ANGPT2-IGF-1R> VL-VH/CL-CH1 exchange antibody mix	2 µg/mL hANGPT2	<Ang-2>mIgG1-Biotin	SA-PE
D	I24	Wildtype mix	2 µg/mL hANGPT2	<Ang-2>mIgG1-Biotin	SA-PE
E	I24	<ANGPT2> wildtype antibody	2 µg/mL hANGPT2	<Ang-2>mIgG1-Biotin	SA-PE
F	I24	<IGF-1R> wildtype antibody	2 µg/mL hANGPT2	<Ang-2>mIgG1-Biotin	SA-PE
G	I24	monospecific <IGF-1R>VL-VH/CL-CH1 exchange antibody	2 µg/mL hANGPT2	<Ang-2>mIgG1-Biotin	SA-PE

Figure 17 Results for Samples A to G 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/CL-CH1 exchange antibody

Sample	Cell IGF-1R	Antibody	hANGPT2	Detection antibody	Detection
A	I24	untreated	-	<Ang-2>mIgG1-Biotin	SA-PE
B	I24	untreated	2 µg/mL hANGPT2	<Ang-2>mIgG1-Biotin	SA-PE
C	I24	Bispecific VL-VH/CL-CH1 exchange mix	2 µg/mL hANGPT2	mIgG1-Biotin-Isotype control	SA-PE
D	I24	Bispecific VL-VH/CL-CH1 exchange mix	2 µg/mL hANGPT2	<Ang-2>mIgG1-Biotin	SA-PE
E	I24	Wildtype mix	2 µg/mL hANGPT2	<Ang-2>mIgG1-Biotin	SA-PE
F	I24	<ANGPT2> wildtype antibody	2 µg/mL hANGPT2	<Ang-2>mIgG1-Biotin	SA-PE
G	I24	<IGF-1R> wildtype antibody	2 µg/mL hANGPT2	<Ang-2>mIgG1-Biotin	SA-PE

Figure 18 Scheme of the IGF-1R ECD binding ELISA

Figure 19 Scheme of the ANGPT2 binding ELISA

Figure 20 Scheme of the VEGF-ANGPT2 bridging ELISA

Figure 21 Scheme of the ANGPT2-VEGF bridging Biacore assay

Figure 22 SDS-PAGE of the purification of <IGF-1R> VL-VH/CL-CH1 exchange antibody, purified <IGF-1R> VL-VH/CL-CH1 exchange antibody corresponds to SEC pool concentrated; B) size exclusion chromatography of the purified <IGF-1R> VL-VH/CL-CH1 exchange antibody

Figure 23 SDS-PAGE of the purification of <ANGPT2> VL-VH/CL-CH1 exchange antibody, purified <ANPT2> VL-VH/CL-CH1 exchange antibody corresponds to SEC pool concentrated); B) size exclusion chromatography of the purified <ANGPT2> VL-VH/CL-CH1 exchange antibody

Figure 24 Binding of monospecific <ANGPt2> VL-VH/CL-CH1 exchange antibody and wildtype <ANGPt2> antibody to ANGPT2 in an ELISA-based binding assay.

Figure 25 Biacore analysis of binding of monospecific <ANGPt2> VL-VH/CL-CH1 exchange antibody and wildtype <ANGPt2> antibody to ANGPT2

Figure 26 SDS-PAGE reduced and non-reduced of the elution fractions from size exclusion chromatography of the bispecific <VEGF-ANGPT2> VL-VH/CL-CH1 exchange antibody

Figure 27 Assignment of bands in SDS-PAGE by mass spectrometry of native fractions. The position of proteins identified by mass spectrometry in the respective unreduced SDS-PAGE is indicated

Figure 28 Analysis of the elution fractions 5 and 9 from size exclusion chromatography of the bispecific <VEGF-ANGPT2> VL-VH/CL-CH1 exchange antibody in the VEGF-ANGPT2 bridging ELISA. A bispecific and tetravalent antibody TvG6-Ang23 recognizing ANGPT2 and VEGF simultaneously is included as positive control.

Figure 29 Surface Plasmon resonance analysis of the elution fractions 5 and 9 from size exclusion chromatography of the bispecific <VEGF-

ANGPT2> VL-VH/CL-CH1 exchange antibody in the VEGF-ANGPT2 bridging Biacore assay. A bispecific and tetravalent antibody TvG6-Ang23 recognizing ANGPT2 and VEGF simultaneously is included as positive control.

Figure 30 Scheme of the bispecific <VEGF-ANGPT2> VL-VH/CL-CH1 exchange antibody with knobs-in-holes for heterodimerization

Figure 31 Biacore analysis of binding of monospecific <ANGPT2> VL-VH(G)/CL-CH1(G) exchange antibody and wildtype <ANGPT2> antibody to ANGPT2

Examples

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

Recombinant DNA techniques

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

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 pPCRScript

(Stratagene) based pGA4 cloning vector. The DNA sequences of the subcloned gene fragments were confirmed by DNA sequencing. Gene synthesis fragments were ordered according to given specifications at Geneart (Regensburg, Germany).

DNA sequence determination

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

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.

Beside the antibody expression cassette the vectors contained:

- an origin of replication which allows replication of this plasmid in E. coli, and

- a ß-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

- 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 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 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).

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 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 µg/ml Geneticin (Gibco). For transfection FuGENE™ 6 Transfection Reagent (Roche Molecular Biochemicals) was used in a ratio of FuGENE™ reagent (µl) to DNA (µg) 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°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 1.0E*6 cells/mL in 600 mL and incubated at 120 rpm, 8% CO2. The day after the cells were transfected at a cell density of ca. 1.5E*6 cells/mL with ca. 42 mL mix of A) 20 mL Opti-MEM (Invitrogen) with 600 µg total plasmid DNA (1 µg/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 µl/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.

Protein determination

The protein concentration of purified antibodies and derivatives 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.

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.

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 KH2PO4, 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 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 Strepatavidin A-96 well microtiter plates (Roche) were coated with 100 µL/well biotinylated anti-human IgG capture molecule F(ab')2<h-Fcγ> BI (Dianova) at 0.1 µg/mL for 1 h at room temperature or alternatively over night at 4°C and subsequently washed three times with 200 µL/well PBS, 0.05% Tween (PBST, Sigma). 100 µL/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 µL/well PBST and bound antibody was detected with 100 µl

F(ab')2<hFcγ>POD (Dianova) at 0.1 µg/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 µL/well PBST and the bound detection antibody was detected by addition of 100 µL 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

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 KH2PO4/K2HPO4, 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

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 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 KH2PO4/K2HPO4, 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 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 Guanidine-hydrochloride 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.

IGF-1R ECD binding ELISA

The binding properties of the generated antibodies were evaluated in an ELISA assay with the IGF-1R extracellular domain (ECD). For this sake the extracellular domain of IGF-1R (residues 1-462) comprising the natural leader sequence and the LI-cysteine rich-12 domains of the human IGF-IR ectodomain of the alpha chain (according to the McKern et al., 1997; Ward et al., 2001) fused to an N-terminal His-Streptavidin binding peptide-tag (His-SBP) was cloned into a pcDNA3 vector derivative and transiently expressed in HEK293F cells. The protein sequence of the IGF-1R-His-SBP ECD is given in SEQ ID NO: 5. StreptaWell High Bind Strepatavidin A-96 well microtiter plates (Roche) were coated with 100 µL/well cell culture supernatant containing soluble IGF-1R-ECD-SBP fusion protein over night at 4°C and washed three times with 200 µL/well PBS, 0.05% Tween (PBST, Sigma). Subsequently, 100 µL/well of a dilution series of the respective antibody and as a reference wildtype <IGF-1R> antibody in PBS (Sigma) including 1% BSA (fraction V, Roche) was added to the wells and incubated for 1-2 h on a microtiterplate shaker at room temperature. For the dilution series either the same amount of purified antibody as a reference or supernatants from transient transfection in HEK293E (HEK293F) normalized by Sandwich-IgG-ELISA for the same antibody concentration were applied to the wells. The wells were washed three times with 200 µL/well PBST and bound antibody was detected with 100 µL/well F(ab')2<hFcγ>POD (Dianova) at 0.1 µg/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 µL/well PBST and the bound detection antibody was detected by addition of 100 µL ABTS/well. Determination of absorbance was performed on a Tecan Fluor Spectrometer at a measurement wavelength of 405 nm (reference wavelength 492 nm).

IGF-1R ECD Biacore

Binding of the generated antibodies to human IGF-1R ECD was also investigated by surface plasmon resonance using a BIACORE T100 instrument (GE Healthcare Biosciences AB, Uppsala, Sweden). Briefly, for affinity measurements Goat-Anti-Human IgG, JIR 109-005-098 antibodies were immobilized on a CM5 chip via amine coupling for presentation of the antibodies against human IGF-1R ECD-Fc tagged. Binding was measured in HBS buffer (HBS-P (10 mM HEPES, 150 mM NaCl, 0.005% Tween 20, ph 7.4), 25°C. IGF-1R ECD (R&D Systems or in house purified) was added in various concentrations in solution. Association was measured by an IGF-1R ECD injection of 80 seconds to 3 minutes; dissociation was measured by washing the chip surface with HBS buffer for 3 - 10 minutes and a KD value was estimated using a 1:1 Langmuir binding model. Due to low loading density and capturing level of <IGF-1R> antibodies monovalent IGF-1R ECD binding was obtained. Negative control data (e.g. buffer curves) were subtracted from sample curves for correction of system intrinsic baseline drift and for noise signal reduction. Biacore T100 Evaluation Software version 1.1.1 was used for analysis of sensorgrams and for calculation of affinity data (Figure 18).

ANGPT2 binding ELISA

The binding properties of the generated antibodies were evaluated in an ELISA assay with full-length ANGPT2-His protein (R&D Systems). For this sake Falcon polystyrene clear enhanced microtiter plates were coated with 100 µl 1 µg/mL recombinant human ANGPT2 (R&D Systems, carrier-free) in PBS for 2 h at room temperature or over night at 4°C. The wells were washed three times with 300µl PBST (0,2% Tween 20) and blocked with 200 µl 2% BSA 0,1% Tween 20 for 30 min at room temperature and subsequently washed three times with 300µl PBST. 100 µL/well of a dilution series of purified <ANGPT2> VL-VH/CL-CH1 exchange antibody and as a reference wildtype <ANGPT2> antibody in PBS (Sigma) were added to the wells and incubated for 1 h on a microtiterplate shaker at room temperature. The wells were washed three times with 300µl PBST (0,2% Tween 20)

and bound antibody was detected with 100 µL/well 0.1 µg/ml F(ab') <hk>POD (Biozol Cat.No. 206005) or 100 µL/well 0.1 µg/ml F(ab') <hFcγ>POD (Immuno research) in 2% BSA 0,1% Tween 20 in 2% BSA 0,1% Tween 20 as detection antibody for 1 h on a microtiterplate shaker at room temperature. Unbound detection antibody was washed away three times with 300 µL/well PBST and the bound detection antibody was detected by addition of 100 µL ABTS/well. Determination of absorbance was performed on a Tecan Fluor Spectrometer at a measurement wavelength of 405 nm (reference wavelength 492 nm).

ANGPT2 binding BIACORE

Binding of the generated antibodies to human ANGPT2 was also investigated by surface plasmon resonance using a BIACORE T100 instrument (GE Healthcare Biosciences AB, Uppsala, Sweden). Briefly, for affinity measurements goat<hIgG-Fcg> polyclonal antibodies were immobilized on a CM5 or CM4 chip via amine coupling for presentation of the antibodies against human ANGPT2. Binding was measured in HBS buffer (HBS-P (10 mM HEPES, 150 mM NaCl, 0.005% Tween 20, ph 7.4), with or without 5 mM Ca2+, 25°C. Purified ANGPT2-His (R&D Systems or in house purified) was added in various concentrations in solution. Association was measured by an ANGPT2-injection of 3 minutes; dissociation was measured by washing the chip surface with HBS buffer for 3 to 5 minutes and a KD value was estimated using a 1:1 Langmuir binding model. Due to heterogenity of the ANGPT2 preparation no 1:1 binding could be observed; KD values are thus only relative estimations. Negative control data (e.g. buffer curves) were subtracted from sample curves for correction of system intrinsic baseline drift and for noise signal reduction. Biacore T100 Evaluation Software version 1.1.1 was used for analysis of sensorgrams and for calculation of affinity data (Figure 19)

Inhibition of hANGPT2 binding to Tie-2-ECD (ELISA)

To test the ability of ANGPT2 antibodies to interfere with Tie2 binding the following ELISA was set up. The test was performed on 384 well microtiter plates (MicroCoat, DE, Cat.No. 464718) at RT. After each incubation step plates were washed 3 times with PBST. At the beginning, plates were coated with 0.5 µg/ml Tie-2 protein (R&D Systems, UK, Cat.No.313-TI) for at least 2 hours

(h).Thereafter the wells were blocked with PBS supplemented with 0.2% Tween-20 and 2% BSA (Roche Diagnostics GmbH, DE) for 1 h. Dilutions of purified antibodies in PBS were incubated together with 0.2 µg/ml huANGPT2 (R&D Systems,UK, Cat.No. 623-AN) for 1 h at RT. After washing a mixture of 0.5 µg/ml biotinylated anti-ANGPT2 clone BAM0981 (R&D Systems,UK) and 1:3000 diluted streptavidin HRP (Roche Diagnostics GmbH, DE, Cat.No.11089153001) was added for 1 h. Thereafter the plates were washed 6 times with PBST. Plates were developed with freshly prepared ABTS reagent (Roche Diagnostics GmbH, DE, buffer #204 530 001, tablets #11 112 422 001) for 30 minutes at RT. Absorbance was measured at 405 nm.

ANGPT2-VEGF bridging ELISA

The binding properties of the generated bispecific antibodies was evaluated in an ELISA assay with immobilized full-length VEGF165-His protein (R&D Systems) and human ANGPT2-His protein (R&D Systems) for detection of simultaneously bound bispecific antibody. Only a bispecific antibody is able to bind simultaneously to VEGF and ANGPT2 and thus bridge the two antigens whereas monospecific "standard" IgG1 antibodies should not be capable of simultaneously binding to VEGF and ANGPT2. For this sake Falcon polystyrene clear enhanced microtiter plates were coated with 100 µl 2 µg/mL recombinant human VEGF165 (R&D Systems) in PBS for 2 h at room temperature or over night at 4°C. The wells were washed three times with 300µl PBST (0,2% Tween 20) and blocked with 200 µl 2% BSA 0,1% Tween 20 for 30 min at room temperature and subsequently washed three times with 300µl PBST. 100 µL/well of a dilution series of purified bispecific antibody and control antibodies in PBS (Sigma) was added to the wells and incubated for 1 h on a microtiterplate shaker at room temperature. The wells were washed three times with 300µl PBST (0,2% Tween 20) and bound antibody was detected by addition of 100 µl 0.5 µg/ml human ANGPT2-His (R&D Systems) in PBS. The wells were washed three times with 300µl PBST (0,2% Tween 20) and bound ANGPT2 was detected with 100 µl 0.5 µg/mL <ANGPT2>mIgG1-Biotin antibody (BAM0981, R&D Systems) for 1 h at room temperature. Unbound detection antibody was washed away with three times 300µl PBST (0,2% Tween 20) and bound antibody was detected by addition of 100 µl 1:2000 Streptavidin-POD

conjugate (Roche Diagnostics GmbH, Cat. No.11089153) 1:4 diluted in blocking buffer for 1h at room temperature. Unbound Streptavidin-POD conjugate was washed away with three-six times 300µl PBST (0,2% Tween 20) and bound Strepatavidin-POD conjugate was detected by addition of 100 µL ABTS/well. Determination of absorbance was performed on a Tecan Fluor Spectrometer at a measurement wavelength of 405 nm (reference wavelength 492 nm) (Figure 20).

Biacore assay to detect simultaneous binding of bispecific antibodies to VEGF and ANGPT2

In order to further corroborate the data from the bridging ELISA an additional assay was established using surface plasmon resonance technology on a Biacore T100 instrument to confirm simultaneous binding to VEGF and ANGPT2 according to the following protocol. Data were analyzed using the T100 software package: ANGPT2 was captured with a capture level of 2000-1700 RU via a PentaHisAntibody (PentaHis-Ab BSA-free, Qiagen No. 34660) that was immobilized on a CM5 chip via amincoupling (BSA-free). HBS-N buffer served as running buffer, activation was done by mixture of EDC/NHS. The PentaHis-Ab BSA-free Capture-Antibody was diluted in coupling buffer NaAc, pH 4.5, c = 30 µg/mL, finally still activated carboxyl groups were blocked by injection of 1 M Ethanolamin, ligand densities of 5000 and 17000 RU were tested. ANGPT2 with a concentration of 500 nM was captured by the PentaHis-Ab at a flow of 5 µL/min diluted with running buffer + 1 mg/mL BSA. Subsequently, bispecific antibody binding to ANGPT2 and to VEGF was demonstrated by incubation with rhVEGF. For this sake, bispecific antibody was bound to ANGPT2 at a flow of 50 µL/min and a concentration of 100-500 nM, diluted with running buffer + 1 mg/mL BSA and simultaneous binding was detected by incubation with VEGF (rhVEGF, R&D-Systems Cat.-No, 293-VE) in PBS + 0.005 % (v/v) Tween20 running buffer + 1 mg/ml BSA at a flow of 50 µL/min and a VEGF concentration of 100-150 nM. Association time 120 sec, dissociation time 1200 sec. Regeneration was done at a flow of 50 µL/min with 2 x 10 mM Glycin pH 2.0 and a contact time of 60 sec. Sensorgrams were corrected using the usual double referencing (control reference: binding of bispecific antibody and rhVEGF to capture molecule PentaHisAb). Blanks for each Ab were measured with rhVEGF concentration "0". A scheme of the Biacore assay is shown in Figure 21. Sensorgrams were corrected using the usual double referencing (control reference: binding of bispecific Ab and rhVEGF to

capture molecule PentaHisAb . Blanks for each Ab were measured with rhVEGF concentration "0".

Examples 1:

Production, expression, purification and characterization of monospecific, bivalent <IGF-1R> antibody, wherein the variable domains VL and VH are replaced by each other, and wherein the constant domains CL and CH1 are replaced by each other (abbreviated herein as <IGF-1R> VL-VH/CL-CH1 exchange antibody).

Example 1A

Making of the expression plasmids for the monospecific, bivalent <IGF-1R> VL-VH/CL-CH1 exchange antibody.

The sequences for the heavy and light chain variable domains of the monospecific, bivalent Insulin-like Growth Factor 1 Receptor <IGF-1R> VL-VH/CL-CH1 exchange antibody including the respective leader sequences described in this example are derived from wild type <IGF-1R> antibody heavy chain (SEQ ID NO: 1, plasmid 4843-pUC-HC-IGF-1R) and a light chain (SEQ ID NO: 2, plasmid 4842-pUC-LC-IGF-1R) described in WO 2005/005635, and the heavy and light chain constant domains are derived from a human antibody (C-kappa and IgG1).

The gene segments encoding the <IGF-1R> 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 γ1-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 <IGF-1R> HC* (Heavy Chain*) (SEQ ID NO: 3) in the following.

The gene segments for the <IGF-1R> antibody leader sequence, heavy chain variable domain (VH) and the human γ1-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 <IGF-1R> LC* (Light Chain)* (SEQ ID NO: 4) in the following.

Figure 5 and Figure 6 show a schematic view of the protein sequence of the modified <IGF-1R> HC* heavy chain* and the modified <IGF-1R> LC* light chain*.

In the following the respective expression vectors are briefly described:

Vector DW047-pUC-HC*-IGF-1R

Vector DW047-pUC-HC*- IGF-1R is an expression plasmid e.g. for transient expression of a <IGF-1R> heavy chain* HC* (cDNA organized expression cassette; with CMV-Intron A in HEK293 (EBNA) cells or for stable expression in CHO cells.

Beside the <IGF-1R> HC* expression cassette this vector contains:

- an origin of replication from the vector pUC18 which allows replication of this plasmid in E. coli, and

- a ß-lactamase gene which confers ampicillin resistance in E. coli.

The transcription unit of the <IGF-1R> HC* gene is composed of the following elements:

- the unique AscI restriction site at the 5'-end

- the immediate early enhancer and promoter from the human cytomegalovirus,

- followed by the Intron A sequence,

- a 5'-untranslated region of a human antibody gene,

- a immunoglobulin light chain signal sequence,

- the human <IGF-1R> mature HC* chain encoding a fusion of the human light chain variable domain (VL) and the human kappa-light chain constant domain (CL) fused to the 5'-end of the Fc domains of the human γ1-heavy chain constant domains (Hinge-CH2-CH3).

- a 3' untranslated region with a polyadenylation signal sequence, and

- the unique restriction site SgrAI at the 3'-end.

The plasmid map of the <IGF-1R> HC* expression vector DW047-pUC-HC*-IGF-1R is shown in Figure 7. The amino acid sequence of the <IGF-1R> HC* (including signal sequence) is given in SEQ ID NO: 3.

Vector DW048-pUC-LC*-IGF-1R

Vector DW048-pUC-LC*-IGF-1R is an expression plasmid e.g. for transient expression of a VL-VH/CL-CH1 exchange <IGF-1R> light chain* LC* (cDNA organized expression cassette; with CMV-Intron A in HEK293 (EBNA) cells or for stable expression in CHO cells.

Beside the <IGF-1R> LC* expression cassette this vector contains:

- an origin of replication from the vector pUC18 which allows replication of this plasmid in E. coli, and

- a ß-lactamase gene which confers ampicillin resistance in E. coli.

The transcription unit of the <IGF-1R> LC* gene is composed of the following elements:

- the unique restriction site Sse8387I at the 5' end

- the immediate early enhancer and promoter from the human cytomegalovirus,

- followed by the Intron A sequence,

- a 5'-untranslated region of a human antibody gene,

- a immunoglobulin heavy chain signal sequence,

- the human <IGF-1R> antibody mature LC* chain encoding a fusion of the human heavy chain variable domain (VH) and the human γ1-heavy chain constant domains (CH1).

- a 3' untranslated region with a polyadenylation signal sequence, and

- the unique restriction sites SalI and FseI at the 3'-end.

The plasmid map of the light chain* <IGF-1R> LC* expression vector DW048-pUC-LC*-IGF-1R is shown in Figure 8. The amino acid sequence of the <IGF-1R> LC* (including signal sequence) is given in SEQ ID NO: 4.

Plasmids DW047-pUC-HC*-IGF-1R and DW048-pUC-LC*-IGF-1R can be used for transient or stable co-transfections e.g. into HEK293, HEK293 EBNA or CHO cells (2-vector system). For comparative reasons the wildtype <IGF-1R> antibody was transiently expressed from plasmids 4842-pUC-LC-IGF-1R (SEQ ID NO: 2) and 4843-pUC-HC-IGF-1R (SEQ ID NO: 1) analogous to the ones described in this example.

In order to achieve higher expression levels in transient expressions in HEK293 EBNA cells the <IGF-1R> HC* expression cassette can be sub-cloned via AscI, SgrAI sites and the <IGF-1R> LC* expression cassette can be sub-cloned via Sse8387I and FseI sites into the 4700 pUC-Hyg_OriP expression vector containing

- an OriP element, and

- a hygromycine resistance gene as a selectable marker.

Heavy and light chain transcription units can either be sub-cloned into two independent 4700-pUC-Hyg-OriP vectors for co-transfection (2-vector system) or they can be cloned into one common 4700-pUC-Hyg-OriP vector (1-vector system) for subsequent transient or stable transfections with the resulting vectors. Figure 9 shows a plasmid map of the basic vector 4700-pUC-OriP.

Example 1B

Making of the monospecific, bivalent <IGF-1R> VL-VH/CL-CH1 exchange antibody expression plasmids

The <IGF-1R> fusion genes (HC* and LC* fusion genes) comprising the exchanged Fab sequences of the wildtype <IGF-1R> antibody were assembled with known recombinant methods and techniques by connection of the according nucleic acid segments.

The nucleic acid sequences encoding the IGF-1R HC* and LC* were each synthesized by chemical synthesis and subsequently cloned into a pPCRScript (Stratagene) based pGA4 cloning vector at Geneart (Regensburg, Germany). The expression cassette encoding the IGF-1R HC* was ligated into the respective E. coli plasmid via PvuII and BmgBI restriction sites resulting in the final vector DW047-pUC-HC*-IGF-1R; the expression cassette encoding the respective IGF-1R LC* was

ligated into the respective E. coli plasmid via PvuII and SalI restriction sites resulting in the final vector DW048-pUC-LC*-IGF-1R. The subcloned nucleic acid sequences were verified by DNA sequencing. For transient and stable transfections larger quantities of the plasmids were prepared by plasmid preparation from transformed E. coli cultures (Nucleobond AX, Macherey-Nagel).

Example 1C

Transient expression of monospecific, bivalent <IGF-1R> VL-VH/CL-CH1 exchange antibody in HEK293 EBNA cells

Recombinant <IGF-1R> VL-VH/CL-CH1 exchange antibody was expressed by transient co-transfection of plasmids DW047-pUC-HC*-IGF-1R and DW048-pUC-LC*-IGF-1R 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 µg/ml Geneticin (Gibco). For transfection FuGENE™ 6 Transfection Reagent (Roche Molecular Biochemicals) was used in a ratio of FuGENE™ reagent (µl) to DNA (µg) of 4:1 (ranging from 3:1 to 6:1). Light and heavy chain plasmids encoding <IGF-1R> HC* and LC* (plasmids DW047-pUC-HC*-IGF-1R and DW048-pUC-LC*-IGF-1R) were expressed from two different plasmids using a molar ratio of light chain to 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]. <IGF-1R> VL-VH/CL-CH1 exchange antibody containing cell culture supernatants were harvested from day 5 to 11 after transfection by centrifugation and stored at -20°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.

Example 1D

Immunoprecipitation of monospecific, bivalent <IGF-1R> VL-VH/CL-CH1 exchange antibody

Monospecific, bivalent <IGF-1R> VL-VH/CL-CH1 exchange antibody was isolated from cell culture supernatants (example 1C) by immunoprecipitation with Protein A Agarose-beads (Roche). 60 µL Protein A Agarose beads were 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, 20 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. Figure 10 shows the SDS-PAGE from a typical immunoprecipitation experiment. The monospecific, bivalent <IGF-1R> VL-VH/CL-CH1 exchange antibody behaves like a typical IgG1 antibody with a ca. 25 kDa band corresponding to the LC* light chain and a 50 kDa band corresponding to the respective HC* heavy chain. In the unreduced state, a band at ca. 150 kDa can be observed for the complete antibody.

Example 1E

Purification of monospecific, bivalent <IGF-1R> VL-VH/CL-CH1 exchange antibody and confirmation of identity by mass spectrometry

The expressed and secreted monospecific, bivalent <IGF-1R> VL-VH/CL-CH1 exchange antibody was purified from filtered cell culture supernatants by Protein A affinity chromatography according to known standard methods. In brief, the <IGF-1R> VL-VH/CL-CH1 exchange antibody containing cell culture supernatants from transient transfections were clarified by centrifugation (10,000 g for 10 minutes) and filtration through a 0.45 µm filter and applied to a Protein A HiTrap MabSelect Xtra column (GE Healthcare) equilibrated with PBS buffer (10 mM Na2HPO4, 1 mM KH2PO4, 137 mM NaCl and 2.7 mM KCl, pH 7.4). Unbound proteins were washed out with PBS equilibration buffer followed by 0.1 M sodium citrate buffer, pH 5.5 and washed with PBS. Elution of <IGF-1R> VL-VH/CL-CH1 exchange

antibody was achieved with 100 mM sodium citrate, pH 2,8 followed by immediate neutralization of the sample with 300µl 2 M Tris pH 9.0 per 2 ml fraction. Aggregated protein was separated from monomeric antibodies by size exclusion chromatography on a HiLoad 26/60 Superdex 200 prep grade column (GE Healthcare) in 20 mM Histidine, 150 mM NaCl pH 6.0 and monomeric antibody fractions were subsequently concentrated using a MILLIPORE Amicon Ultra-15 centrifugal concentrator. <IGF-1R> VL-VH/CL-CH1 exchange antibody was frozen and stored at -20°C or -80°C. The integrity of the <IGF-1R> VL-VH/CL-CH1 exchange was analyzed by SDS-PAGE in the presence and absence of a reducing agent and subsequent staining with Coomassie brilliant blue as described in Example 1D. The purified <IGF-1R> VL-VH/CL-CH1 exchange antibody behaves like a typical IgG1 antibody with a ca. 25 kDa band corresponding to the LC* light chain and a 50 kDa band corresponding to the respective HC* heavy chain. In the unreduced state a band at ca. 150 kDa can be observed for the complete antibody. Aggregation and oligomeric state of the <IGF-1R> VL-VH/CL-CH1 exchange antibody was analyzed by analytical size exclusion chromatography and showed that the purified Fab crossover antibody was in a monomeric state. Characterized samples were provided for subsequent protein analytics and functional characterization. ESI mass spectrometry confirmed the theoretical molecular mass (calculated without C-terminal lysine residue of the heavy chain and with a C-terminal pyroglutamate residue of the light chain) of the completely deglycosylated <IGF-1R> VL-VH/CL-CH1 exchange antibody as main species. (Figure 22)

Example 1F

Analysis of the IGF-1R binding properties of monospecific, bivalent <IGF-1R> VL-VH/CL-CH1 exchange antibody in an IGF-1R ECD binding ELISA and by Biacore

The binding properties of monospecific, bivalent <IGF-1R> VL-VH/CL-CH1 exchange antibody were evaluated in an ELISA assay with the IGF-1R extracellular domain (ECD) as described above. Figure 11 shows the normalized results from a titration of <IGF-1R> VL-VH/CL-CH1 exchange antibody and wildtype <IGF-1R> antibody from transient transfection supernatants in HEK293E by Sandwich-IgG-ELISA. It can be clearly seen that <IGF-1R> VL-VH/CL-CH1 exchange antibody is functional and shows comparable binding characteristics as the wildtype <IGF-1R> antibody and thus appears fully functional. The minor observed differences lie

within the error of the method and might e.g. result from minor variances in protein concentration.

These findings were corroborated by Biacore data with the respective purified antibodies that showed that monospecific, bivalent <IGF-1R> VL-VH/CL-CH1 exchange antibody had a comparable affinity and binding kinetics for IGF-1R ECD as the original wildtype antibody within the error of the method. The kinetic data are given in the following table:

	ka [1/Ms]	*kd [1/s]*	*K(D) [M]*
wildtype <IGF-1R> antibody	**3.18E+06**	**5.521E-3**	**1.74E-09**
<IGF-1R> VL-VH/CL-CH1 exchange antibody	2.65E+06	6.258E-3	2.36E-09

Example 1G

Analysis of the IGF-1R binding properties of monospecific, bivalent <IGF-1R> VL-VH/CL-CH1 exchange antibody by FACS with IGF-1R over-expressing I24 cells

In order to confirm the binding activity of <IGF-1R> VL-VH/CL-CH1 exchange antibody binding to the IGF-1R over-expressed on the surface of I24 cells (NIH3T3 cells expressing recombinant human IGF-1R, Roche) is studied by FACS. Briefly, 5x10E5 I24cells per FACS tube are incubated with a dilution of purified <IGF-1R> VL-VH/CL-CH1 exchange antibody and wildtype <IGF-1R> antibody as a reference and incubated on ice for 1 h. Unbound antibody is washed away with 4 ml ice cold PBS (Gibco) + 2% FCS (Gibco). Subsequently, cells are centrifuged (5 min at 400 g) and bound antibody is detected with F(ab')2 <hFcγ>PE conjugate (Dianova) on ice for 1 h protected from light. Unbound detection antibody is washed away with 4 ml ice cold PBS + 2% FCS. Subsequently, cells are centrifuged (5 min 400 g), resuspended in 300-500 µL PBS and bound detection antibody 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. Binding of <IGF-1R> VL-VH/CL-CH1 exchange antibody and wildtype <IGF-1R> reference antibody to IGF-1R on I24 cells is compared via concentration dependent shift of mean fluorescence intensity.

Additional experiments showed that <IGF-1R> VL-VH/CL-CH1 exchange antibody also retained their activity to induce the internalization of IGF-1R on MCF7 cells and had only low ADCC activity on DU145 cells if incubated with human PBMCs comparable to the wildtype <IGF-1R> antibody

Taken together the experiments in example 1 showed that using the domain exchange fully functional antibodies with properties comparable to wildtype antibodies can be generated. All functional properties were retained in biochemical and cellular assays. These antibodies with domain exchange form the basis for the generation of bispecific antibodies as described below.

Examples 2:

Production, expression, purification and characterization of monospecific, bivalent <ANGPT2> antibody, wherein the variable domains VL and VH are replaced by each other, and wherein the constant domains CL and CH1 are replaced by each other (abbreviated herein as <ANGPT2> VL-VH/CL-CH1 exchange antibody).

Example 2A

Making of the expression plasmids for the monospecific, bivalent <ANGPT2> VL-VH/CL-CH1 exchange antibody variant

The sequences for the heavy and light chain variable domains of a monospecific, bivalent Angiopoietin-2 <ANGPT2> VL-VH/CL-CH1 exchange antibody including the respective leader sequences described in this example are derived from a human <ANGPT2> antibody heavy chain (SEQ ID NO: 6) and a light chain (SEQ ID NO: 7) described in WO 2006/045049 and the heavy and light chain constant domains are derived from a human antibody (C-kappa and IgG1).

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 γ1-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 <ANGPT2> HC* (heavy chain*) (SEQ ID NO: 8) in the following.

The gene segments for the <ANGPT2> antibody leader sequence, heavy chain variable domain (VH) and the human γ1-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 <ANGPT2> LC* (light chain*)(SEQ ID NO: 9) in the following.

The respective expression vectors are analogous to the ones described in example 1A. The plasmid map of the heavy chain* <ANGPT2> HC* expression vector pUC-HC*-ANGPT2> is shown in Figure 12. The amino acid sequence of the <ANGPT2> HC* (including signal sequence) is given in SEQ ID NO: 8.

The plasmid map of the light chain* <ANGPT2> LC* expression vector pUC-LC*-ANGPT2> is shown in Figure 13. The amino acid sequence of the <ANGPT2> LC* (including signal sequence) is given in SEQ ID NO: 9.Plasmids pUC-HC*-ANGPT2> and pUC-LC*-ANGPT2> can be used for transient or stable co-transfections e.g. into HEK293-F, HEK293 EBNA or CHO cells (2-vector system).

In order to achieve higher expression levels in transient expressions in HEK293 EBNA cells the <ANGPT2> HC* expression cassette can be sub-cloned via AscI, SgrAI sites and the <ANGPT2> LC* expression cassette can be sub-cloned via Sse8387I and FseI sites into the 4700 pUC-Hyg_OriP expression vector as described in example 1A. Heavy and light chain transcription units can either be sub-cloned into two independent 4700-pUC-Hyg-OriP vectors for co-transfection (2-vector system) or they can be cloned into one common 4700-pUC-Hyg-OriP vector (1-vector system) for subsequent transient or stable transfections with the resulting vectors via FseI, SgrAI, Sse8387I and AscI sites.

The wildtype <ANGPT2> antibody was cloned into plasmids SB04-pUC-HC-ANGPT2 (SEQ ID NO: 6) and SB06-pUC-LC-ANGPT2 (SEQ ID NO: 7) that are analogous to the vectors described in this and previous example 1A. The transcription units for the wildtype <ANGPT2> antibody heavy and light chains were sub-cloned from plasmids SB04-pUC-HC-ANGPT2 and SB06-pUC-LC-ANGPT2 basic vectors via FseI, SgrAI, Sse8387I and AscI sites into plasmids SB07-pUC-Hyg-OriP-HC-ANGPT2 and SB09-pUC-Hyg-OriP-LC-ANGPT2 in order to

achieve higher transient expression levels in HEK293E cells. For comparative reasons and for co-expression experiments (see example 3) the wildtype <ANGPT2> antibody was either transiently (co-) expressed from plasmids SB07-pUC-Hyg-OriP-HC-ANGPT2 and SB09-pUC-Hyg-OriP-LC-ANGPT2 or from plasmids SB04-pUC-HC-ANGPT2 and SB06-pUC-LC-ANGPT2.

Example 2B

Making of the monospecific, bivalent <ANGPT2> VL-VH/CL-CH1 exchange antibody expression plasmids

The <ANGPT2> VL-VH/CL-CH1 exchange antibody fusion genes (HC* and LC* fusion genes) comprising the exchanged Fab sequences of the wildtype <ANGPT2> antibody were assembled with known recombinant methods and techniques by connection of the according nucleic acid segments.

The nucleic acid sequences encoding the <ANGPT2> VL-VH/CL-CH1 exchange antibody HC* and LC* were each synthesized by chemical synthesis and subsequently cloned into a pPCRScript (Stratagene) based pGA4 cloning vector at Geneart (Regensburg, Germany). The expression cassette encoding the <ANGPT2> VL-VH/CL-CH1 exchange antibody HC* was ligated into the respective E. coli plasmid via PstI and EcoNI restriction sites resulting in the final vector pUC-HC*-<ANGPT2>; the expression cassette encoding the respective <ANGPT2> LC* was ligated into the respective E. coli plasmid via PvuII and FseI restriction sites resulting in the final vector pUC-LC*-<ANGPT2>. The subcloned nucleic acid sequences was verified by DNA sequencing. For transient and stable transfections larger quantities of the plasmids were prepared by plasmid preparation from transformed E. coli cultures (Nucleobond AX, Macherey-Nagel)

Example 2C

Transient expression of monospecific, bivalent <ANGPT2> VL-VH/CL-CH1 exchange antibody in HEK293 EBNA cells

Recombinant <ANGPT2> VL-VH/CL-CH1 exchange antibody was expressed by transient co-transfection of plasmids pUC-HC*-ANGPT2> and pUC-LC*-ANGPT2> 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 µg/ml Geneticin (Gibco). For transfection FuGENE™ 6 Transfection Reagent (Roche Molecular Biochemicals) was used in a ratio of FuGENE™ reagent (µl) to DNA (µg) of 4:1 (ranging from 3:1 to 6:1). Light and heavy chain plasmids encoding <ANGPT2> HC* and LC* (plasmids pUC-HC*-ANGPT2> and pUC-LC*-ANGPT2>) were expressed from two different plasmids using a molar ratio of light chain to 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]. <ANGPT2> VL-VH/CL-CH1 exchange antibody containing cell culture supernatants were harvested from day 5 to 11 after transfection by centrifugation and stored at -20°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.

Example 2D

Purification of monospecific, bivalent <ANGPT2> VL-VH/CL-CH1 exchange antibody and confirmation of identity by mass spectrometry

The expressed and secreted monospecific, bivalent <ANGPT2> VL-VH/CL-CH1 exchange antibody was purified from filtered cell culture supernatants by Protein A affinity chromatography according to known standard methods. In brief, the <ANGPT2> VL-VH/CL-CH1 exchange antibody containing cell culture supernatants from transient transfections were clarified by centrifugation (10,000 g for 10 minutes) and filtration through a 0.45 µm filter and applied to a Protein A HiTrap MabSelect Xtra column (GE Healthcare) equilibrated with PBS buffer (10 mM Na2HPO4, 1 mM KH2PO4, 137 mM NaCl and 2.7 mM KCl, pH 7.4). Unbound proteins were washed out with PBS equilibration buffer followed by 0.1 M sodium citrate buffer, pH 5.5 and washed with PBS. Elution of VL-VH/CL-CH1 exchange antibody was achieved with 100 mM sodium citrate, pH 2,8 followed by immediate neutralization of the sample with 300µl 2 M Tris pH 9.0 per 2 ml fraction. Aggregated protein was separated from monomeric antibodies by size exclusion chromatography on a HiLoad 26/60 Superdex 200 prep grade column (GE Healthcare) in 20 mM Histidine, 150 mM NaCl pH 6.0 and monomeric

antibody fractions were subsequently concentrated using a MILLIPORE Amicon Ultra-15 centrifugal concentrator. <ANGPT2> VL-VH/CL-CH1 exchange antibody was frozen and stored at -20°C or -80°C. The integrity of the <ANGPT2> VL-VH/CL-CH1 exchange antibody was analyzed by SDS-PAGE in the presence and absence of a reducing agent and subsequent staining with Coomassie brilliant blue (Figure 23-A). Aggregation and oligomeric state of the <ANGPT2> VL-VH/CL-CH1 exchange antibody was analyzed by analytical size exclusion chromatography (Figure 23-B). Characterized samples were provided for subsequent protein analytics and functional characterization. ESI mass spectrometry confirmed the theoretical molecular mass of the completely deglycosylated <ANGPT2> VL-VH/CL-CH1 exchange antibody as main species. No contamination by antibody-like proteins could be observed.

Example 2F

Analysis of the <ANGPT2> binding properties of monospecific, bivalent <ANGPT2> VL-VH/CL-CH1 exchange antibody in an <ANGPT2> binding ELISA and by Biacore

The binding properties of monospecific, bivalent <ANGPT2> VL-VH/CL-CH1 exchange antibody were evaluated in an ELISA assay with full-length ANGPT2>-His protein (R&D Systems) as described above. Figure 24 shows the results from a titration of purified <IGF-1R> VL-VH/CL-CH1 exchange antibody and wildtype <IGF-1R> antibody in the sandwich binding ELISA. It can be clearly seen that <ANGPT> VL-VH/CL-CH1 exchange antibody is functional and shows comparable binding properties as the wildtype <ANGPT2> antibody and thus appears fully functional. The minor observed differences lie within the error of the methid and might e.g. result from minor variances in protein concentration.

These findings were corroborated by Biacore data with the respective purified antibodies that showed that monospecific, bivalent <ANGPT2> VL-VH/CL-CH1 exchange antibody with a KD value of 13 pM had a comparable affinity and binding kinetics for ANGPT2 within the error of the method as the original wildtype <ANGPT2> antibody with a KD value of 12 pM (Figure 25)

Example 2G

Analysis of the functional properties of monospecific, bivalent <ANGPT2> VL-VH/CL-CH1 exchange antibody

In order to show that the monospecific, bivalent <ANGPT2> VL-VH/CL-CH1 exchange antibody has functional properties comparable to the original wildtype <ANGPT2> antibody the two antibodies were compared for their ability to interfere with binding of ANGPT2 to its Tie2 receptor extracellular domain in an ELISA binding assay as described above. In the respective binding ELISA <ANGPT2> VL-VH/CL-CH1 exchange antibody had an EC50 value of 135 ng/ml for interference with binding of human ANGPT2 which is comparable to the EC50 value of 145 nM for the original wildtype <ANGPT2> antibody. These data were confirmed in a cellular ligand binding competition assay with HEK293 cells over-expressing Tie2 on their surface where <ANGPT2> VL-VH/CL-CH1 exchange antibody had an EC50 value of 225 ng/ml for interference with binding of human ANGPT2 which is comparable to the EC50 value of 205 nM for the original wildtype <ANGPT2> antibody (data not shown).

Taken together the experiments in example 2 showed that using the domain exchange fully functional antibodies with properties comparable to wildtype antibodies can be generated. All functional properties were retained in biochemical and cellular assays. These antibodies with domain exchange form the basis for the generation of bispecific antibodies as described below in examples 3 and 4.

Example 2H

A molecular modeling analysis of the antibodies with domain exchange revelaed that the steric room between the exchanged domains could be limiting folding. Therefore constructs were designed in which an additional Glycine residue was introduced at the C-terminus of the exchanged domains of the Fab e.g. between the VL-CL and Hinge connecting region or at the end of free VH-CH1 domain respectively. The respective monospecific, bivalent antibody is dentoted as <ANGPT2> VL-VH(G)/CL-CH1(G) exchange antibody in the following.

The sequences for the heavy and light chain variable domains of a monospecific, bivalent Angiopoietin-2 <ANGPT2> VL-VH/CL-CH1 exchange antibody including the respective leader sequences described in this example are derived from a human

<ANGPT2> antibody heavy chain (SEQ ID NO: 6) and a light chain (SEQ ID NO: 7) described in WO 2006/045049 and the heavy and light chain constant domains are derived from a human antibody (C-kappa and IgG1).

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 γ1-heavy chain constant domains (Hinge-CH2-CH3) and including an additional Glycine residue. 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 <ANGPT2> HC(G)* (heavy chain*) (SEQ ID NO: 17) in the following.

The gene segments for the <ANGPT2> antibody leader sequence, heavy chain variable domain (VH) and the human γ1-heavy chain constant domains (CH1) were joined as independent chain including an additional Glycine residue. 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 <ANGPT2> LC(G)* (light chain*)(SEQ ID NO: 18) in the following.

The respective expression vectors are analogous to the ones described in examples 2 above. Subsequently, these expression vectors were used for the transient co-expression of the respective <ANGPT2> VL-VH(G)/CL-CH1(G) antibody with domain exchange in HEK293-F cells. The respective <ANGPT2> VL-VH(G)/CL-CH1(G) exchange antibody was purified from transient expression as described above and analyzed by SDS-PAGE, size exclusion chromatography and mass spectrometry of the respective antibody. Protein expression yields were good and similar to the expression yields obtained for the conventional VL-VH/CL-CH1 exchange antibody described above. All properties investigated showed no unexpected findings and were essentially comparable to the respective <ANGPT2 wildtype antibody. Figure 31 demonstrates the virtually comparable poperties of the <ANGPT2> wildtype antibody and the <ANGPT2> VL-VH(G)/CL-CH1(G) antibody in an ANGPT2 Biacore binding assay. Within the error of the method both antibodies exhibited a comparable binding affinity for human ANGPT2 with estimated KD values (mean from two determinations) of ca. 38 pM for the <ANGPT2> wildtype antibody and ca. 45 pM for the <ANGPT2> VL-VH(G)/CL-CH1(G) antibody.

	ka [1/Ms]	*kd [1/s]*	*K(D) [M]*
wildtype <ANGPT2> antibody	5.26 E+05	2.0 E-4	3.79E-10
<ANGPT2> VL-VH(G)/CL-CH1(G) exchange antibody	5.29 E+06	2.358 E-3	4.45 E-09

Examples 3

Expression of bispecific, bivalent <ANGPT2-IGF-1R> antibody, wherein in the heavy and light chain specifically binding to IGF-1R, the variable domains VL and VH are replaced by each other, and the constant domains CL and CH1 are replaced by each other (abbreviated herein as <ANGPT2-IGF-1R> VL-VH/CL-CH1 exchange antibody).

Example 3A

Transient co-expression of <ANGPT2> wildtype antibody and <IGF-1R> VL-VH/CL-CH1 exchange antibody in HEK293 EBNA cells to yield bispecific <ANGPT2-IGF-1R> VL-VH/CL-CH1 exchange antibody

In order to generate a functional bispecific antibody recognizing <ANGPT2> via the <ANGPT2> wildtype Fab region on one side and IGF-1R via the <IGF-1R> VL-VH/CL-CH1 exchange antibody Fab region on the other side the two expression plasmids coding for the <IGF-1R> VL-VH/CL-CH1 exchange antibody (example 1A) were co-expressed with two expression plasmids coding for the <ANGPT2> wildtype antibody. (example 2A). Assuming a statistical association of wildtype heavy chains HC and Fab crossover heavy chains HC*this resulted in the generation of bispecific and bivalent <ANGPT2-IGF-1R> VL-VH/CL-CH1 exchange antibody. Under the assumption that both antibodies are equally well expressed and without taking side products into account this should have resulted in a 1:2:1 ratio of the three main products monospecific <IGF-1R> VL-VH/CL-CH1 exchange antibody, bispecific <ANGPT2-IGF-1R> VL-VH/CL-CH1 exchange antibody, and <ANGPT2> wildtype antibody. In addition, several side products such as LC-LC* (Fab2 fragment), HC-HC* (monovalent antibody) and HC*-LC dimers can be expected.

In contrast, when co-expressing the two expression plasmids coding for the <IGF-1R> wildtype antibody (example 1A) and the two expression plasmids coding for the <ANGPT2> wildtype antibody as a reference only a small proportion of functional bispecific <IGF-1R-ANGPT2> antibody will be generated due to the statistical association of the heavy chains but the unguided association of light chains with both heavy chains from the <IGF-1R> and <ANGPT2> wildtype antibodies.

To generate the mix of the main products A) monospecific <IGF-1R> VL-VH/CL-CH1 exchange antibody, B) bispecific <ANGPT2-IGF-1R> VL-VH/CL-CH1 exchange antibody and C)<ANGPT2> wildtype antibodies the four plasmids DW047-pUC-HC*-IGF-1R and DW048-pUC-LC*-IGF-1R and either plasmids SB07-pUC-Hyg-OriP-HC-ANGPT2 and SB09-pUC-Hyg-OriP-LC-ANGPT2 (or plasmids SB04-pUC-HC-ANGPT2 and SB06-pUC-LC-ANGPT2) were transiently co-transfected 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 µg/ml Geneticin (Gibco). For transfection FuGENE™ 6 Transfection Reagent (Roche Molecular Biochemicals) was used in a ratio of FuGENE™ reagent (µl) to DNA (µg) of 4:1 (ranging from 3:1 to 6:1). Light and heavy chain plasmids encoding <IGF-1R> HC* and LC* (plasmids DW047-pUC-HC*-IGF-1R and DW048-pUC-LC*-IGF-1R) and <ANGPT2> HC and LC (plasmids SB07-pUC-Hyg-OriP-HC-ANGPT2 and SB09-pUC-Hyg-OriP-LC-ANGPT2 or plasmids SB04-pUC-HC-ANGPT2 and SB06-pUC-LC-ANGPT2, respectively) were expressed from four different plasmids using a molar ratio of light chains to heavy chains encoding plasmids of 1:1 (equimolar). Cells were feeded at day 3 with L-Glutamine ad 4 mM, Glucose [Sigma] and NAA [Gibco]. The harvested supernatant contained a mix of the main products A) monospecific <IGF-1R> VL-VH/CL-CH1 exchange antibody, B) bispecific <ANGPT2-IGF-1R> VL-VH/CL-CH1 exchange antibody and C)<ANGPT2> wildtype antibodies and is denoted as "Bispecific VL-VH/CL-CH1 exchange mix". Bispecific VL-VH/CL-CH1 exchange mix containing cell culture supernatants, were harvested from day 5 to 11 after transfection by centrifugation and stored at -20°C.

For comparative reasons the wildtype <IGF-1R> antibody was transiently co-expressed from HC and LC plasmids (4842-pUC-LC-IGF-1R and 4843-pUC-HC-IGF-1R, example 1A) together with the wildtype <ANGPT2> HC and LC plasmids (SB07-pUC-Hyg-OriP-HC-ANGPT2 and SB09-pUC-Hyg-OriP-LC-ANGPT2 or SB04-pUC-HC-ANGPT2 and SB06-pUC-LC-ANGPT2, respectively). Cells were feeded at day 3 with L-Glutamine ad 4 mM, Glucose [Sigma] and NAA [Gibco]. The harvested supernatant contained a mix of different <IGF-1R> and <ANGPT2> wildtype antibody variants either monospecific, bispecific or binding incompetent due to the unguided association of light chains with both heavy chains from the <IGF-1R> and <ANGPT2> wildtype antibodies resulting in wrong light chain association, and is denoted as "wildtype mix". Wildtype mix containing cell culture supernatants, were harvested from day 5 to 11 after transfection by centrifugation and stored at -20°C.

As the <ANGPT2> wildtype antibody shows significantly higher expression transient expression yields than the <IGF-1R> wildtype and <IGF-1R> Fab crossover antibodies the ratio of <ANGPT2> wildtype antibody plasmids and <IGF-1R> VL-VH/CL-CH1 exchange antibody plasmids was shifted in favour of the expression of <ANGPT2> wildtype antibody. The plasmid ratio has to be adapted during future experiments to allow an equal expression of both specificities resulting in a more even distribution of the different antibodies.

Example 3B

Immunoprecipitation of bispecific <ANGPT2-IGF-1R> VL-VH/CL-CH1 exchange antibody

A mix of the main products A) monospecific <IGF-1R> VL-VH/CL-CH1 exchange antibody, B) bispecific <ANGPT2-IGF-1R> VL-VH/CL-CH1 exchange antibody and C)<ANGPT2> wildtype antibodies ("Bispecific VL-VH/CL-CH1 exchange mix") was isolated from cell culture supernatants (example 3A) by immunoprecipitation with Protein A Agarose-beads (Roche). 60 µL Protein A Agarose beads were 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, 20 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. On the SDS-PAGE no difference between the three antibody species could be seen. All antibodies behaved like typical IgG1 antibodies with a ca. 25 kDa band corresponding to the light chains and a 50 kDa band corresponding to the respective heavy chains. In the unreduced state, a band at ca. 150 kDa could be observed for the complete antibody. Thus, in order to prove the presence of functional bispecific <ANGPT2-IGF-1R> VL-VH/CL-CH1 exchange antibody the crossover mix of the three antibody species was purified (example 3C) and a cellular FACS bridging assay was designed (example 3D).

Example 3C

Purification of bispecific <ANGPT2-IGF-1R> VL-VH/CL-CH1 exchange antibody

The mix of the main products A) monospecific <IGF-1R> VL-VH/CL-CH1 exchange antibody, B) bispecific <ANGPT2-IGF-1R> VL-VH/CL-CH1 exchange antibody and C)<ANGPT2> wildtype antibodies ("Bispecific VL-VH/CL-CH1 exchange mix") from example 3A was purified from filtered cell culture supernatants by Protein A affinity chromatography followed by size exclusion chromatography according to known standard methods. In brief, the antibody mix containing cell culture supernatants from transient transfections of plasmids DW047-pUC-HC*-IGF-1R and DW048-pUC-LC*-IGF-1R and SB07-pUC-Hyg-OriP-HC-ANGPT2 and SB09-pUC-Hyg-OriP-LC-ANGPT2 were clarified by centrifugation (10,000 g for 10 minutes) and filtration through a 0.45 µm filter and applied to a Protein A HiTrap MabSelect Xtra column (GE Healthcare) equilibrated with PBS buffer (10 mM Na2HPO4, 1 mM KH2PO4, 137 mM NaCl and 2.7 mM KCl, pH 7.4). Unbound proteins were washed out with PBS equilibration buffer followed by 0.1 M sodium citrate buffer, pH 5.5 and washed with PBS. Elution of bispecific <ANGPT2-IGF-1R> VL-VH/CL-CH1 exchange antibody was achieved

with 100 mM sodium citrate, pH 2,8 followed by immediate neutralization of the sample with 300µl 2 M Tris pH 9.0 per 2 ml fraction. Aggregated protein was separated from monomeric antibodies by size exclusion chromatography on a HiLoad 26/60 Superdex 200 prep grade column (GE Healthcare) in 20 mM Histidine, 150 mM NaCl pH 6.0 and monomeric antibody fractions were subsequently concentrated using a MILLIPORE Amicon Ultra-15 centrifugal concentrator. The VL-VH/CL-CH1 exchange mix was frozen and stored at -20°C or -80°C. The integrity of the antibody species was analyzed by SDS-PAGE (see Fig. 14) in the presence and absence of a reducing agent and subsequent staining with Coomassie brilliant blue as described in Example 1D. The antibody mix behaved like typical IgG1 antibodies with a ca. 25 kDa band corresponding to the light chains and a 50 kDa band corresponding to the respective heavy chains. In the unreduced state a band at ca. 150 kDa could be observed for the complete antibody. No obvious side-products such as monovalent antibodies etc. were visible from the SDS-PAGE after Protein A purification. Aggregation and oligomeric state of the bispecific <ANGPT2-IGF-1R> VL-VH/CL-CH1 exchange antibody was analyzed by analytical size exclusion chromatography and showed that the purified antibody species were in a monomeric state. Characterized samples were provided for subsequent protein analytics and functional characterization. In order to prove the presence of functional bispecific <ANGPT2-IGF-1R> VL-VH/CL-CH1 exchange antibody the mix of the three antibody species was analyzed in a cellular FACS bridging assay (example 3D).

For comparative reasons the wildtype mix resulting from the co-expression of wildtype <IGF-1R> antibody HC and LC plasmids (4842-pUC-LC-IGF-1R and 4843-pUC-HC-IGF-1R, example 1A) together with the wildtype <ANGPT2> HC and LC plasmids (SB07-pUC-Hyg-OriP-HC-ANGPT2 and SB09-pUC-Hyg-OriP-LC-ANGPT2) was purified as a reference from filtered cell culture supernatants by Protein A affinity chromatography followed by size exclusion chromatography according to the described procedure.

Example 3D

Detection of functional bispecific <ANGPT2-IGF-1R> VL-VH/CL-CH1 exchange antibody in a cellular FACS bridging assay on I24 IGF-1R expressing cells

In order to confirm the presence of functional bispecific <ANGPT2-IGF-1R> VL-VH/CL-CH1 exchange antibody in the "Bispecific VL-VH/CL-CH1 exchange mix" of the main products A) monospecific <IGF-1R> VL-VH/CL-CH1 exchange antibody, B) bispecific <ANGPT2-IGF-1R> VL-VH/CL-CH1 exchange antibody and C)<ANGPT2> wildtype antibodies from the transient co-expression described in example 3A, a cellular FACS IGF-1R-ANGPT2 bridging assay on I24 cells (NIH3T3 cells expressing recombinant human IGF-1R, Roche) was performed. The assay principle is depicted in Fig. 15. A bispecific <ANGPT2-IGF-1R> VL-VH/CL-CH1 exchange antibody that is present in the supernatant (example 3A) or in the purified antibody mix (example 3C), 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.

Briefly, 5x10E5 I24cells per FACS tube were incubated with either 50 µL undiluted cell culture supernatant or with a 160 µg/mL dilution of total purified antibody mix and incubated on ice for 1h. In the first case the cells were incubated with A) cell culture supernatants from the co-expression of the crossover <IGF-1R> plasmids (DW047-pUC-HC*-IGF-1R and DW048-pUC-LC*-IGF-1R) with the wildtype <ANGPT2> plasmids (SB04-pUC-HC-ANGPT2> and SB06-pUC-LC-ANGPT2) denoted as "Bispecific VL-VH/CL-CH1 exchange mix" or B) with cell culture supernatant from the co-expression of the wildtype <IGF-1R> plasmids (4842-pUC-LC-IGF-1R and 4843-pUC-HC-IGF-1R) with the wildtype <ANGPT2> plasmids (SB04-pUC-HC-ANGPT2> and SB06-pUC-LC-ANGPT2) denoted as "Wildtype mix" (Figure 16). In the second case, the respective purified antibody mix from either Bispecific VL-VH/CL-CH1 exchange mix or from Wildtype mix was applied to the I24 cells (example 3C, Figure 17). Unbound antibody was washed away with 4 ml ice cold PBS (Gibco) + 2% FCS (Gibco), cells were centrifuged (5 min at 400 g) and bound bispecific antibody was detected with 50 µl 2 µg/mL human Angiopoietin-2 (ANGPT2) (R&D Systems) for 1 h on ice. Subsequently, unbound Angiopoietin-2 (ANGPT2) was washed away once (Fig. 16) or twice (Fig. 17) with 4 ml ice cold PBS (Gibco) + 2% FCS (Gibco), cells were centrifuged (5 min at 400 g) and bound Angiopoietin-2 was detected with 50 µl 5 µg/mL <Ang-2>mIgG1-Biotin antibody (BAM0981, R&D Systems) for 45 min on ice; alternatively, cells were incubated with 50 µl 5 µg/mL mIgG1-Biotin-Isotype control (R&D Systems). Unbound detection antibody was washed away with 4 ml ice cold PBS (Gibco) + 2% FCS (Gibco), cells were centrifuged (5 min at 400 g) and bound detection antibody was detected with 50 µl 1:400 Streptavidin-PE conjugate

(Invitrogen/Zymed) for 45 min on ice protected from light. Unbound Streptavidin-PE conjugate was washed away with 4 ml ice cold PBS + 2% FCS. Subsequently, cells were centrifuged (5 min 400 g), resuspended in 300-500 µL PBS and bound Streptavidin-PE conjugate was quantified on a FACSCalibur or FACS Canto (BD (FL2 channel, 10.000 cells per acquisition). During the experiment the respective isotype controls were included to exclude any unspecific binding events. In addition, purified monospecific, bivalent IgG1 antibodies <IGF-1R> and <ANGPT2> were included as controls.

Fig. 16 shows the results from the cellular FACS bridging assay on I24 cells with cell culture supernatants; Fig. 17 shows the results with the purified antibody mix. In both cases in which the VL-VH/CL-CH1 exchange technology was applied, the incubation with supernatant or purified antibody "Bispecific VL-VH/CL-CH1 exchange mix" from the co-expression of a VL-VH/CL-CH1 exchange antibody with a wildtype antibody resulted in a significant shift in fluorescence indicating the presence of a functional bispecific <ANGPT2-IGF-1R> VL-VH/CL-CH1 exchange antibody that is capable of binding to IGF-1R in I24 cells and to ANGPT2 simultaneously; and thus bridges its two target antigens with the two opposed Fab regions. In contrast to this and as predicted for the co-expression of two wildtype antibodies, only a very small proportion of functional bispecific antibodies is formed resulting in only a slight shift in fluorescence in the FACS bridging assay when the cell culture supernatant or purified antibody "Wildtype mix" from the co-expression of the wildtype <IGF-1R> plasmids with the wildtype <ANGPT2> plasmids was applied indicating the presence of only a small fraction of functional bispecific <IGF-1R-ANGPT2> wildtype antibody.

These results show that by co-expression of VL-VH/CL-CH1 exchange plasmids coding for a <IGF-1R> antibody with wildtype plasmids coding for a <ANGPT2> antibody functional bispecific <ANGPT2-IGF-1R> VL-VH/CL-CH1 exchange antibody recognizing the two different targets simultaneously can easily be generated. In contrast, the co-expression of two wildtype plasmids coding for <IGF-1R> and <ANGPT2> antibodies results in a high complexity of the formed antibodies and only a minor proportion of functional bispecific <IGF-1R-ANGPT2> wildtype antibody.

Example 4

Generation of bivalent, bispecific <VEGF-ANGPT2> VL-VH/CL-CH1 exchange antibody with modified CH3 domains (knobs-into-holes) (Figure 30)

As shown in the example above the co-expression of plasmids coding for wildtype antibodies with plasmids coding for VL-VH/CL-CH1 exchange antibodies results in the generation of a bispecific VL-VH/CL-CH1 exchange mix of the main products A) monospecific VL-VH/CL-CH1 exchange antibody, B) bispecific VL-VH/CL-CH1 exchange antibody and C) wildtype antibody. To further improve the yield of the bispecific <VEGF-ANGPT2> VL-VH/CL-CH1 exchange antibody the knobs-into-holes technology was applied to the co-expression of a <ANGPT2> VL-VH/CL-CH1 exchange antibody and a wildtype <VEGF> antibody to foster heterodimerization of the respective unmodified and modified heavy chains (via HC and HC*) and obtain a more homogenous and functional bispecific antibody preparation. In this example a bispecific antibody recognizing VEGF and ANGPT2 simultaneously based on the <VEGF> wildtype antibody G6-31 and the VL-VH/CL-CH1 exchange <ANGPT2> antibody Mab536 as described above was generated.

As described above 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 humanγ1-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 <ANGPT2> HC* (heavy chain*) (SEQ ID NO: 8).

The gene segments for the <ANGPT2> antibody leader sequence, heavy chain variable domain (VH) and the human g1-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 <ANGPT2> LC* (light chain*)(SEQ ID NO: 9) in the following.

The sequences for the wildtype heavy and light chain variable domains of the monospecific, bivalent <VEGF> wildtype antibody G6-31 including the respective

leader sequences described in this example are derived from the human <VEGF> antibody G6-31 heavy chain variable domains of SEQ ID NO: 12 and the light chain variable domains of SEQ ID NO: 13 which are both derived from the human phage display derived anti-VEGF antibody G6-31 which is described in detail in Liang et al., J Biol Chem. 2006 Jan 13;281(2):951-61 and in US 2007/0141065 and the heavy and light chain constant domains are derived from a human antibody (C-kappa and IgG1).

For this purpose, the plasmid coding for the for the heavy chain of the <VEGF> wildtype antibody G6-31 was modified by introduction of a CH3 gene segment generated by gene synthesis and coding for the knobs residue T366W of the SEQ ID NO: 10 into the CH3 domain of the respective <VEGF> wildtype antibody G6-31 heavy chain resulting in SEQ ID NO: 16; in contrast the plasmid coding for the heavy chain* HC* of the VL-VH/CL-CH1 exchange <ANGPT2> antibody Mab536 was modified by introduction of a CH3 gene segment generated by gene synthesis and coding for the hole residues T366S, L368A, Y407V of the SEQ ID NO: 11 into the CH3 domain of the respective VL-VH/CL-CH1 exchange <ANGPT2> antibody Mab536 heavy chain* HC* resulting in SEQ ID NO: 15. In this case plasmids coding for the wildtype <VEGF> knobs antibody G6-31 were organized as genomic vectors whereas the plasmids for the VL-VH/CL-CH1 exchange <ANGPT2> antibody Mab536 were organized as IntronA-cDNA vectors.

Subsequently the respective four plasmids coding for <VEGF> G6-31 heavy chain HC with knob SEQ ID NO: 16 and wildtype light chain LC SEQ ID NO: 14, and the modified VL-VH/CL-CH1 exchange <ANGPT> heavy chain* HC* with hole SEQ ID NO: 15 and modified light chain* LC* (SEQ ID NO: 8) were co-expressed in an equimolar ratio by transient transfections in the HEK293-F system as described above in a 2.6 L scale in a Quad fermenter. Antibodies were purified via a HiTrap MabSelect column (GE) followed by size exclusion chromatography on a HiLoad Superdex 200 26/60 column (GE) as described above. Yields after SEC were in the range of ca. 38 mg purified antibody fractions from 2L transient expression.. Figure 26 shows a reduced and non-reduced SDS-PAGE of the size exclusion fractions obtained during the purification. On the reduced SDS-PAGE it can be seen that the respective wildtype and modified heavy and light chains have been synthesized and

purified homogeneously. However, on the non-reduced SDS-PAGE it is obvious that there were still several antibody species present.

In the following the obtained size exclusion fractions were analyzed by mass spectrometry (either deglycosylated, but not reduced or deglycosylated and reduced). Several antibody species could be identified in the fractions by mass spectrometry and could also be assigned to the bands that are seen on the respective SDS-PAGE (Figure 27). The following table shows the antibody species that could be identified:

Species	1. Run Frac 5 deglyc.	1. Run Frac 9 deglyc.
LC G6-31/ 23255 Da / (SS): 23251 Da	-	-
HC G6-31/ 49149 Da /(SS):49136 Da	-	-
LC* VL-VH/CL-CH1 exchange <ANGPT2> antibody / 23919 Da/ (SS): 23914 Da	-	-
HC* VL-VH/CL-CH1 exchange <ANGPT2> antibody Mab536/ 49245 Da/ (SS): 49231 Da	-	
LC G6-31 + LC VL-VH/CL-CH1 exchange <ANGPT2> antibody Mab536 => (SS): 47165 Da	X	X
Complete Ab G6-31(SS) 144774 Da	X	
Complete Ab bispecific <VEGF-ANGPT2> VL-VH/CL-CH1 exchange antibody (SS) 145532 Da (LC+ HC G6-31) + (LC* + HC*)	X	
½ Ab G6-31 (SS) 72387 Da	X	X
(HC G6-31) + (HC VL-VH/CL-CH1 exchange <ANGPT2> antibody Mab536)=> (SS) 98367 Da	X	X
(SH) 2 x (HC VL-VH/CL-CH1 exchange <ANGPT2> antibody Mab536) + LC G6-31 => 121745 Da	X	
2 x (HC G6-31) + LC G6-31 + HC VL-VH/CL-CH1 exchange <ANGPT2> antibody Mab536 =>(SS):170754 Da	X + 20 Da	

The desired bispecific <VEGF-ANGPT2> VL-VH/CL-CH1 exchange antibody recognizing VEGF with one arm and ANGPT2 with the other arm could thus be unequivocally be identified by mass spectrometry and could also be seen on the respective SDS-PAGE. A schematic scheme of the desired bispecific <VEGF-ANGPT2> VL-VH/CL-CH1 exchange antibody is seen in Figure 30. The highest concentration of this desired antibody could be found in fractions 5 and 6 whereas its concentration was reduced in latter fractions.

In addition, the presence of bispecific <VEGF-ANGPT2> VL-VH/CL-CH1 exchange antibody capable of binding simultaneously to ANGPT2 and VEGF was confirmed by an ELISA bridging assay (Figure 28) and a Biacore bridging assays (Figure 29) described above showing that the desired bispecific antibody was capable of binding to ANGPT2 and VEGF simultaneously. In these assays a tetravalent bispecific antibody TvG6-Ang23 served as a control.

It should be noted that due to a relative over-expression of the wildtype <VEGF> antibody G6-31 e.g. due to better expression yields for the genomic vectors coding for G6-31 derivatives the formation of inactive side products was fostered resulting in an excess of inactive G6-31 dimers and half antibodies. In order to achieve a maximal yield of the desired bispecific <VEGF-ANGPT2> VL-VH/CL-CH1 exchange antibody additional studies are ongoing that achieve a uniform expression of all four antibody chains and reduce side product formation. These studies include i) the optimization of the equimolar stochiometry of the 4 plasmids used for o-expression e.g. by combining the transcriptional units on one or two plasmids, the introduction of the respective control elements; as well ii) the optimization of heterodimerization e.g. by using different knobs-in-holes technologies such as the introduction of an additional disulfide bridge into the CH3 domain e.g. Y349C into the "knobs chain" and D356C into the "hole chain" and/or combined with the use of residues R409D; K370E (K409D) for knobs residues and D399K; E357K for hole residues described by EP 1870459A1.

Patent Claims

1. A bivalent, bispecific antibody, comprising:

a) the light chain and heavy chain of an antibody specifically binding to a first antigen; and

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

wherein the variable domains VL and VH are replaced by each other,

and

wherein the constant domains CL and CH1 are replaced by each other.

2. The antibody according to claim 1, characterized in that

the CH3 domain of one heavy chain and the CH3 domain of the other heavy chain each meet at an interface which comprises an original interface between the antibody CH3 domains;

wherein said interface is altered to promote the formation of the bivalent, bispecific antibody, wherein the alteration is characterized in that:

a) the CH3 domain of one heavy chain is altered,
so that within the original interface the CH3 domain of one heavy chain that meets the original interface of the CH3 domain of the other heavy chain within the bivalent, bispecific antibody,
an amino acid residue is replaced with an amino acid residue having a larger side chain volume, thereby generating a protuberance within the interface of the CH3 domain of one heavy chain which is positionable in a cavity within the interface of the CH3 domain of the other heavy chain

and

b) the CH3 domain of the other heavy chain is altered,
so that within the original interface of the second CH3 domain that meets the original interface of the first CH3 domain within the bivalent, bispecific antibody
an amino acid residue is replaced with an amino acid residue having a

smaller side chain volume, thereby generating a cavity within the interface of the second CH3 domain within which a protuberance within the interface of the first CH3 domain is positionable.

3. The antibody according to claim 2, characterized in that

said amino acid residue having a larger side chain volume is selected from the group consisting of arginine (R), phenylalanine (F), tyrosine (Y), tryptophan (W).

4. The antibody according to any one of claims 2 or 3, characterized in that

said amino acid residue having a smaller side chain volume is selected from the group consisting of alanine (A), serine (S), threonine (T), valine (V).

5. The antibody according to any one of claims 2 to 4, characterized in that

both CH3 domains are further altered by the introduction of cysteine (C) as amino acid in the corresponding positions of each CH3 domain.

6. The antibody according to claim 1, characterized in that

one of the constant heavy chain domains CH3 of both heavy chains is replaced by a constant heavy chain domain CH1; and the other constant heavy chain domain CH3 is replaced by a constant light chain domain CL.

7. 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 and heavy chain of an antibody specifically binding to a first antigen, and

-vectors comprising nucleic acid molecules encoding the light chain and heavy chain of an antibody specifically binding to a second antigen,
wherein the variable domains VL and VH are replaced by each other,
and
wherein the constant domains CL and CH1 are replaced by each other;

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

c) recovering said antibody molecule from said culture.

8. A host cell comprising:

-vectors comprising nucleic acid molecules encoding the light chain and heavy chain of an antibody specifically binding to a first antigen, and

-vectors comprising nucleic acid molecules encoding the light chain and heavy chain of an antibody specifically binding to a second antigen,

wherein the variable domains VL and VH are replaced by each other,

and

wherein the constant domains CL and CH1 are replaced by each other.

9. A composition, preferably a pharmaceutical or a diagnostic composition of the bivalent, bispecific antibody according to claims 1 to 6

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